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# Interim Criteria for Polymer-Modified Bituminous Roofing Membrane Materials

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NIST BUILDING SCIENCE SERIES 167

# Interim Criteria for Polymer-Modified Bituminous Roofing Membrane Materials

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## ABSTRACT

This report presents the results of a study to develop interim criteria for the selection of polymer-modified bituminous roofing membrane materials. The criteria are based on a review of existing standard specifications and related documents. They are intended for use by the construction agencies of the Department of Defense in specifying polymer-modified bituminous roofing membrane materials until voluntary consensus standards are developed in the United States.

The suggested interim criteria are generally presented using a performance criteria format. The membrane characteristics for which performance criteria are suggested are: dimensional stability, fire, flow resistance, hail impact, moisture content and absorption, pliability, strain energy, uplift resistance, and weathering resistance (heat exposure). Prescriptive criteria for five membrane characteristics are used to complement the suggested performance criteria. The approach of using complementary prescriptive criteria is taken to incorporate in the performance criteria tests methods which can be relatively rapidly performed for characterization or identification of the membrane material.

Other membrane requirements are listed for future development of criteria, but performance criteria for these requirements are not suggested at the present. Lack of a consistent database in the existing standards and related documents precludes suggesting criteria at this time. It is considered beneficial to present the needed criteria as a first step toward directing future research for standards development for polymer-modified bituminous roofing membrane materials.

**Key words:** characteristics; membranes; low-sloped roofing; performance criteria; prescriptive criteria; polymer-modified bitumens; properties; roofs; test methods

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## EXECUTIVE SUMMARY

The use of low-sloped roof membranes fabricated from polymer-modified bituminous materials has been increasing in the United States. From little use a decade ago, U.S. annual installation of modified bitumens is now reported to be about 16 percent of membrane roofing. Some projections indicate that their use by 1990 will be in the range of 27 to 33 percent of the area of membranes installed.

A major problem for the U.S. roofing industry has been the lack of consensus standards and criteria for selection and use of the polymer-modified bituminous roofing membrane materials. Although performance has generally been satisfactory for the limited period of time that they have been available, the rapid growth in use has raised questions concerning long-term performance of materials which may enter the market without adequate evaluation. Although consensus standards and related criteria for selection and use of the modified bitumens are not yet available in the United States, many documents have been developed in North America and Europe which might provide the starting point for the U.S. industry. Also, a draft ASTM standard on methods for sampling and testing modified bitumens has been extensively reviewed by an ASTM Subcommittee and is near to consensus agreement at the Subcommittee level.

The construction agencies of the U.S. Department of Defense (DOD) consider that benefits are to be gained in having available alternative materials for fabricating membranes for low-sloped roofing systems. However, they are reluctant to use the newer membrane materials such as the modified bitumens without having available selection criteria for guide specifications or other construction documents. The development of such criteria through ASTM or other industry organizations is not expected to be complete for many months. Thus, DOD requested that the National Institute of Standards and Technology (NIST) (formerly National Bureau of Standards/NBS) conduct a study to provide interim criteria for use in military guide specifications. This report presents the results of the study.

The objectives of this report are: 1) to provide a listing of documents that pertain to the development of selection criteria for modified bitumens, and to summarize the characteristics evaluated in the documents, 2) to suggest selection criteria that may be used by the DOD construction agencies in the absence of voluntary consensus standards in the United States, and 3) to provide data that may assist in the development of voluntary consensus standards. The scope of the study focused on a review of standards and related documents which could serve as the basis for the development of interim selection criteria.

As a first step in providing data to support the development of the suggested criteria, limited testing was conducted using typical commercially available modified bitumens. Data on the following properties are reported for five unaged membrane materials: thickness, tensile strength, elongation, low-temperature flexibility, tear resistance, dimensional stability, moisture content, and strain energy. In addition, data on tensile strength, elongation, low-temperature flexibility, and strain energy are reported after exposure of the membrane materials to the heat and ultraviolet conditions given in the ASTM draft.

The criteria are divided into two categories: 1) prescriptive criteria concerning the characterization of the material as manufactured, and 2) performance criteria concerning properties associated with in-service behavior. A performance specification defines a product in terms of the functions it is to perform; whereas a prescriptive specification defines a product in terms of its constituents and their relationships to each other. One benefit of prescriptive criteria is that they provide a means to assure that the product reaching the market has the selected property values agreed upon between seller and buyer. Moreover, test methods for prescriptive criteria are often more practical than performance tests for routine product characterization. The criteria suggested herein are primarily in performance criteria format, but are complemented with prescriptive criteria.

In the development of the criteria suggested herein, chief consideration was given to the use of test methods under review by ASTM. This approach was taken in order to promote compatibility between interim criteria suggested in the present report and voluntary consensus requirements likely to be recommended by ASTM Committee D08.

Table 1 presents the suggested prescriptive requirements associated with the selected tests given in the ASTM draft. The suggestion for these requirements is that the average measured property values of the membrane product, as supplied to the user, should not be less than (or where appropriate, greater than) a given percentage of the nominal values as stated by the manufacturer (perhaps in the product literature or in the *NRCA Materials Guide*) for the membrane material. This approach is considered more practical for assuring that the material supplied to a DOD agency is that normally produced by the manufacturer, than if the requirement specified a minimum property value. The requirements for thickness, low-temperature flexibility, and tear resistance have included a suggested limiting value for the membrane products.

**Table 1. Summary of suggested prescriptive criteria for modified bitumens**

Requirement	Test Method	Criterion
Thickness	ASTM draft, Sec. 5	not <5% of the nominal value, 40 mil (1 mm) minimum
Load, max.	ASTM draft, Sec. 6	not <15% of the nominal value
Elongation (max. load)	ASTM draft, Sec. 6	not <20% of the nominal value
Elongation (break)	ASTM draft, Sec. 6	not <20% of the nominal value
Low-Temperature Flexibility	ASTM draft, Sec. 11	not >5 °F (3 °C) of nominal, 25 °F (−4 °C) maximum
Tear Resistance	ASTM draft, Sec. 7	not <20% of the nominal value 30 lbf (130 N) minimum

The suggested performance criteria are presented in the format developed in Building Science Series 55, which suggested preliminary performance criteria for bituminous built-up membrane materials. This format has four key elements: requirement, criterion, test method, and commentary. The membrane and system characteristics for which criteria are suggested are: dimensional stability, fire resistance, flow resistance, hail impact resistance, moisture content and absorption, pliability, strain energy, uplift resistance, and weathering resistance (heat exposure). Some of the performance criteria, notably those on fire, flow, hail, strain energy, and uplift pertain to the modified bitumen as used in the roof system. The criteria incorporating system tests are summarized in table 2. The remaining criteria are specific to the membrane material alone, and are summarized in table 3. As a practical consideration, tests of the membrane material alone may be more readily conducted on a routine basis than membrane system tests.

**Table 2. Summary of suggested performance criteria for modified bitumens incorporating membrane system tests**

Requirement	Test Method	Criterion
Fire Resistance	ASTM, UL, or FM test	conform to applicable code
Flow Resistance	UEAtc No. 27 Sec. 5.1.7	no slippage
Hail Impact	NBS BSS 55  or ASTM D 3746	1.5 in (38 mm) hail stone at 112 ft/s (34 m/s) without water penetration  22 lbf·ft (30 J) without water penetration
Strain Energy	ASTM draft, Sec. 6	not less than 3 lbf·in/in <sup>2</sup> (0.5 kN·m/m <sup>2</sup> )
Uplift	ASTM, UL, or FM test	conform to applicable code

**Table 3.** Summary of suggested performance criteria for modified bitumens incorporating membrane material tests

Requirement	Test Method	Criterion
Dimensional Stability	ASTM draft, Sec. 10	max. change, $\pm 1\%$
Moisture Absorp.	ASTM draft, Sec. 9	1 gram (per specimen), max.
Moisture Content	ASTM draft, Sec. 8	0.5% by mass, max.
Pliability	a) ASTM draft, Sec. 11	no cracking at temperatures of application
	b) UEAtc No. 27 Sec. 5.4.3	no cracking or tearing when unrolled at 32 °F (0 °C)
Weather Resist. Heat Exposure	ASTM draft, Sec. 12	15% max. change of load-elongation; low-temperature flexibility not to exceed 32 °F (0 °C); strain energy not less than 3 lbf·in/in <sup>2</sup> (0.5 kN·m/m <sup>2</sup> ).

The interim criteria suggested in the present report are not complete. When the study was initiated, it was realized that gaps would probably exist in the initial criteria proposed on the basis of a review of existing information. It was thought, at the time, that the available database for the characterization and evaluation of modified bitumens would be insufficient to support a complete set of criteria. The membrane requirements for which criteria are considered to be needed, but were not developed in the present report are: cyclic (substrate) movement resistance, durability of protective surfacings, puncture resistance, seam strength, slippage resistance of base flashings, tear resistance, water transmission resistance, and weather resistance (except heat exposure). Because of the importance of having criteria for these requirements, an initial step in outlining performance criteria using the standard format was undertaken, but the criteria themselves were not proposed. A benefit in presenting this outline of needed criteria is to define the gaps for future criteria development and the needs for research to develop performance data. As future development of the criteria continues, the results should be incorporated in DOD guide specifications.





# 1. INTRODUCTION

## 1.1 Background

The use of low-sloped roof membranes fabricated from polymer-modified bituminous materials has been increasing in the United States. A polymer-modified bituminous roofing membrane material<sup>1</sup> has been described as a factory-prefabricated, reinforced sheet, composed basically of bitumen, reinforcement, and various bitumen modifiers [1]. The modifiers are intended to extend the useful temperature range of the bitumen by lowering the brittle point and raising the softening point [2]. A practical advantage of modified bitumens for roof membranes is that, being bituminous, they closely resemble built-up roofing and are compatible with existing built-up roofing construction details [2-4].

Modified bitumens for use as membranes for low-sloped roofs had their origins in Europe in the 1960s [1,5]. The present U.S. technology was, for the most part, imported from Europe in the 1970s at which time manufacturing began here [1]. The introduction of the modified bitumens occurred concurrently with the single-ply revolution in the U.S. roofing industry, when alternatives to conventional built-up roofing were sought [6]. Interestingly, as described by Johnson [1], the modified bitumen membranes are normally not used as true "single-ply," but are usually employed with a base ply. Nevertheless, some are applied in single-ply configuration. From little use a decade ago, U.S. annual installation of modified bitumens is now about 16 percent of membrane roofing [7]. Some projections indicate that their use by 1990 will be in the range of 27 to 33 percent of the area of membranes installed [5]. As an illustration of the rapid growth, the National Roofing Contractors Association's *Roofing Materials Guide* [8] indicated that, in August 1987, 158 modified bitumen products were available, whereas in February 1983, the number was 34.

Baxter [9] has recently reviewed the field performance of modified bitumen membrane systems. He stated that the overall performance has been acceptable, although not without problems. Some of the problems that he described were rupturing, slippage, blistering, separations at membrane flashing junctures, and lap separation and delamination. The CIB/RILEM<sup>2</sup> Committee on Elastomeric, Thermoplastic, and Modified Bituminous Roofing also has reported on performance [10]. The Committee members described performance as generally being good to excellent. They indicated that problems experienced included some rupturing, blistering, shrinkage, and seam separation.

A major problem for the U.S. roofing industry has been the lack of consensus standards and criteria for selection and use of the polymer-modified bituminous roofing membrane materials [9]. Although performance has been generally satisfactory for the limited period of time that they have been available, the rapid growth in use has raised questions concerning long-term performance of materials which may enter the market without adequate evaluation [11]. Although consensus standards and related criteria for selection and use of the modified bitumens are not yet available in the United States, many documents [12-17] have been developed in North America and Europe which might provide the starting point for the U.S. industry. Also, a draft ASTM standard on methods for sampling and testing modified bitumens is presently under Subcommittee review [18].

The construction agencies of the U.S. Department of Defense (DOD) consider that benefits are to be gained in having available alternative materials for fabricating membranes for low-sloped roofing systems. However, they are reluctant to use the newer membrane materials such as the modified bitumens without having available selection criteria for guide specifications or other construction documents. The development of such criteria through ASTM or other industry organizations is not expected to be complete for many months. Thus, DOD requested that the National Institute of Standards and Technology (NIST) (formerly National Bureau of Standards/NBS) conduct a study to provide interim criteria for use in military guide specifications. This report presents the results of the study.

<sup>1</sup> These materials are frequently referred to as "modified bitumens," which is a term often used in this report.

<sup>2</sup> CIB is a French acronym for Conseil International du Batiment pour la Recherche l'Etude et la Documentation; RILEM is a French acronym for Réunion Internationale des Laboratoires d'Essais et de Recherches sur les Matériaux et les Constructions.

## 1.2 Objectives

The objectives of this report are:

- to provide a listing of documents that pertain to the development of selection criteria for modified bitumens, and to summarize the characteristics evaluated in the documents,
- to suggest selection criteria that may be used by the DOD construction agencies in the absence of voluntary consensus standards in the United States,
- to provide data that may assist in the development of voluntary consensus standards.

## 1.3 Scope of the Study

The scope of the study focused on a review of standards and related documents (see sec. 2) which may serve as the basis for the development of interim selection criteria. As a first step in providing data to support the development of the suggested criteria, limited testing was conducted using typical commercially available modified bitumens.

The interim criteria suggested in the present report are not complete. When the study was initiated, it was realized that gaps would probably exist in the initial criteria proposed on the basis of a review of existing information. It was thought, at the time, that the available database for the characterization and evaluation of modified bitumens would be insufficient to support a complete set of criteria. For example, differing criteria on the same membrane property may be presented in two or more of the reference documents (existing standards), making it difficult to select one over the other on an interim basis without supporting laboratory testing. The gaps in the suggested criteria represent areas where research may be needed.

## 1.4 Performance Specifications

The criteria suggested herein are generally presented in performance criteria format, as developed for roofing membrane materials by Mathey and Cullen [12]. A performance specification defines a product in terms of the functions it is to perform; whereas a prescriptive specification defines a product in terms of its constituents and their relationships to each other [19]. A performance specification is considered to describe a product less narrowly than a prescriptive specification. Nevertheless, as discussed by Frohnsdorff et al. [19], prescriptive specifications frequently have the benefit of incorporating analyses (test methods) which can be conducted more rapidly than performance tests. In this regard, prescriptive specifications may be used for generic product characterization or identification. The criteria suggested herein are primarily in performance criteria format, but are complemented with prescriptive criteria.

### 1.4.1 Performance Criteria Format

The format used for presentation of the suggested performance criteria is that developed for bituminous built-up membranes in 1974 by Mathey and Cullen [12]. Their format for the performance approach had four key elements:

1. *the requirement* — a qualitative statement which describes what the membrane was to accomplish.
2. *the criterion* — a quantitative expression of the level of performance which the membrane should have to perform acceptably.
3. *the test* — the test method which was used to determine that the membrane conformed to the stated criterion.
4. *commentary* — to provide comment concerning an explanation of the reason for, or intent of, the stated criteria.



## 1.5 Modifiers and Reinforcements for Modified Bitumens

The production of polymer-modified bituminous roofing membrane materials has been described in the literature [1-4]. The two primary modifiers currently used are: atactic polypropylene (APP) polymer and styrene-butadiene-styrene (SBS) block copolymer [3]. The APP modifier has constituted about 25 to 30 percent of the bitumen blend; whereas the SBS modifier has comprised about 8 to 14 percent of the blend [3]. The APP modifier is a plastomer, while the SBS modifier is an elastomer. In general, as described by Meynard [2], the modified bitumen displays elastomeric properties if the modifier is an elastomer, and plastic properties if the modifier is a plastomer. As a consequence, the elastomer-modified bitumens are usually more flexible and have greater elasticity at low temperatures; whereas the plastomer-modified bitumens are stiffer and have greater resistance to high temperatures [2].

The two major reinforcing mats used in polymer-modified bituminous roofing membrane materials are fibrous glass and polyester [2]. These reinforcements may be incorporated alone or together. As a consequence, the available membrane materials exhibit a wide variety of load-elongation properties ranging from high-strength/low-elongation to low-strength/high-elongation.

In conducting this study to present preliminary load-elongation and other criteria, the differences in modifiers and reinforcements were considered. However, in keeping with the performance concept, the suggested criteria are not divided along product lines varying by either modifier or reinforcement.

## 2. STANDARDS AND RELATED DOCUMENTS FOR POLYMER-MODIFIED BITUMINOUS ROOFING MEMBRANE MATERIALS

As indicated in the introduction, a number of standards and related documents have been developed for polymer-modified bitumens. It was considered that these documents could provide the basis for interim criteria for DOD use until a voluntary consensus standard is available in the United States. The standards and related documents reviewed during the present study, which formed the basis of the suggested criteria, are listed in table 4. As is evident, table 4 includes reference to the draft ASTM document<sup>3</sup> on methods of test for the modified bitumens.

Table 4. Documents containing criteria applicable to bituminous roofing membranes

Designation	Title	Reference
BSS 55	Preliminary Performance Criteria for Bituminous Membrane Roofing	[12]
UEAtc/Gen	General Directive for the Assessment of Roof Waterproofing Systems	[13]
UEAtc/SBS	Special Directives for the Assessment of Reinforced Homogeneous Waterproofing Coverings of Styrene-Butadiene-Styrene (SBS) Elastomer Bitumen	[14]
UEAtc/APP	Special Directives for the Assessment of Reinforced Waterproofing Coverings of Atactic Polypropylene (APP) Polymer Bitumen	[15]
MRCA	Recommended Performance Criteria for Modified Bitumen Roof Membrane Systems	[16]
CGSB	Standard for Membrane, Modified, Bituminous, Prefabricated, and Reinforced for Roofing	[17]
ASTM draft	Standard Test Methods for Sampling and Evaluating Modified Bituminous Materials for Roofing and Waterproofing	[18]

<sup>3</sup> Used with the permission of the Chairman of ASTM Committee D08, which has responsibility for the draft.

Table 5 presents a summary of the requirements incorporated in the standards and related documents of interest. Note that the majority of the requirements pertain to the properties of the finished membrane material. Other requirements are specific to a factory-applied membrane surfacing, the polymer-bitumen blend alone, and the reinforcement used for the sheet material.

Table 5. Summary of requirements given in the documents containing criteria applicable to bituminous roofing membranes

Requirement	Document						
	BSS 55	UEAtc Gen	UEAtc SBS	UEAtc APP	MRCA MB	CGSB	ASTM draft
Thickness			x	x			x
Width			x	x			
Mass per Area			x	x			
Tensile Strength	x		x	x	x	x	x
Elongation			x	x	x	x	x
Strain Energy					x	x	x
Thermal Expansion	x					x	
Dimen. Stability		x	x	x			x
Shrinkage			x	x			
High Temp Stability							x
Flexural Strength	x						
Fatigue Strength	x		x	x			
Puncture—Static		x	x	x	x	x	
Puncture—Dynamic	x	x	x	x	x	x	
Impact	x				x		
Abrasion					x		
Water Transmission		x			x		
Moisture Content							x
Moisture Absorption					x	x	x
Tear Resistance		x	x	x			x
Pliability (low-temp flex)		x	x	x	x	x	x
Permeability		x	x	x	x	x	
Weathering Resist. (durability)		x	x	x	x	x	x
Heat Resistance			x	x	x		x
Chemical Resistance					x		
Seam Strength		x	x	x	x	x	
Seam Leakage		x	x	x			
Flow Resistance		x	x	x	x		
Thermal Shock	x	x	x	x	x		
Cyclic Movement		x			x	x	
Plant Growth		x					
Temp-Induced Load					x		
Fire	x	x	x	x	x		
Uplift (Wind)	x	x	x	x	x		
Peel (Wind)		x	x	x			
Peel (Wind)		x	x	x			
Foil Integrity					x x		
Granule Embedment			x	x		x	x
Coating Fines			x	x			
Softening Point			x	x			
Penetration				x			
Low-Temp. Flex.			x	x			
Elastic Recovery			x	x			
Reinfor. Mass			x	x			
Stress/Elongation			x	x			

From table 5, it is evident that the requirements for testing considered in the ASTM draft have been included in many of the other documents referenced. Two exceptions are high-temperature stability and moisture content which appear only in the ASTM draft. Because the primary intent of the ASTM draft is to recommend test methods for characterization of membrane material as it is manufactured, the ASTM document does not include systems-related tests such as puncture resistance, cyclic movement, and strength of seams.

In the development of the criteria suggested herein, chief consideration was given to the use of test methods under review by ASTM. This approach was taken in order to promote compatibility between interim criteria suggested in the present report and voluntary consensus requirements likely to be recommended by ASTM Committee D08. As the present report was under preparation, the ASTM draft was near to consensus agreement at the Subcommittee level. It has been widely debated, and few future changes are expected. To support the use of the ASTM draft methods in the suggested criteria, some preliminary testing was conducted in the present study. The results of the tests conducted are presented in Appendix A.

### **3. SUGGESTED INTERIM CRITERIA**

This section of the report presents interim criteria to assist in the selection and use of polymer-modified bituminous roofing membrane materials. The criteria are divided into two categories: 1) prescriptive criteria concerning the characterization of the material as manufactured, and 2) performance criteria concerning properties associated with in-service behavior. In addition, a third category is provided whereby performance requirements are listed, but the associated criteria are not yet suggested. In the latter case, as mentioned, it was considered that sufficient data were not available to support suggesting criteria at this time.

#### **3.1 Prescriptive Requirements for Characterization**

Polymer-modified bituminous roofing membrane materials are produced in plants where quality control procedures may be applied to ascertain that they have certain physical, mechanical, and chemical properties. A key step in the quality control process is testing used to characterize the product. Quality control testing is beneficial to both the manufacturer and consumer. Among other factors, it assures a degree of uniformity of the product, and consistent properties from batch to batch. However, in the case of U.S. roofing products, specifications based on the quality control tests historically provide only prescriptive criteria used to characterize the manufactured product, and do not consider the performance requirements of the membrane material in service [20].

One benefit of prescriptive criteria is that they provide a means to assure that the product reaching the market has the selected property values agreed upon between seller and buyer. Moreover, as Frohnsdorff et al. [19] indicated, test methods for prescriptive criteria are often more practical than performance tests for routine product characterization.

Some requirements may serve a dual role, relating both to prescriptive characterization and performance of the material. An example is low-temperature flexibility. In this case, a product, as manufactured, may have a low-temperature flexibility inherently lower than that needed to perform satisfactorily under expected service conditions. Two ways of specifying the property value are apparent. First, the actual low-temperature flexibility point may be specified as a means of product identification or characterization. Second, the specification may reference the low-temperature flexibility point considered necessary for acceptable performance, which any material should meet.

Quality control tests have been developed in Europe to characterize the properties of modified bitumens [14,15]. Not only are the composite sheets characterized through these tests, but also the individual components comprising the sheets such as reinforcements, modified-bitumen binder, and protective surfacings.



Examples of the prescriptive characterization tests in the UEAtc documents (table 5) for polymer modified bitumens include [14,15]:

A) Membranes

- thickness
- width of sheet
- mass per unit area
- tensile strength and elongation at break
- tearing strength
- low-temperature flexibility

B) Polymer-Bitumen Blend

- fines content
- ring-and-ball softening point
- low-temperature flexibility
- elastic recovery

C) Reinforcements

- nature
- mass per unit area
- ultimate stress and elongation at break

At present, the ASTM draft document [18] on modified bitumens has included a number of tests considered in the category of prescriptive requirements for membrane material characterization. The tests are:

- thickness,
- tensile load,
- tensile elongation,
- low-temperature flexibility, and
- tear resistance.

Requirements for characterizing modified bitumens using these five properties are included in the interim criteria as a complement to the suggested performance criteria.

From table 5 it may be noted that the list of requirements in the ASTM draft is less than those from the UEAtc documents for APP- and SBS-modified bitumens [14,15]. A contributing factor is that the UEAtc requires characterization of the bitumen blend and reinforcement, as well as the composite sheet. Consideration of requirements for bitumen blends and reinforcements was beyond the scope of the present study. Future modification of the criteria suggested herein could consider inclusion of requirements pertaining to the polymer-bitumen blend or the reinforcement, as was done in Europe.

Table 6 presents the suggested prescriptive requirements associated with the selected tests given in the ASTM draft. As seen in table 6, the requirements for thickness, tensile load, tensile elongation, low-temperature flexibility, and tear resistance are that the average<sup>4</sup> measured property values of the membrane product, as supplied to the user, should not be less than (or where appropriate, greater than) a given percentage of the stated nominal values as described by the manufacturer (perhaps in the product literature or in the *NRCA Materials Guide*) for the membrane material. This approach is considered more practical for assuring that the material supplied to a DOD agency is that normally produced by the manufacturer, than if the requirement specified a minimum property value. For example, take a hypothetical case that a sheet material have a required minimum thickness of 0.12 in (3 mm). In this example, a product usually manufactured at 0.16 in (4 mm) could be supplied at a thickness 25 percent thinner than normally produced, and still meet a specification calling for a 0.12 in (3 mm) minimum.

Note that, in table 6, the requirements for thickness, low-temperature flexibility, and tear resistance have included a suggested limiting value for all products. These limiting values were based on the results of tests in this study for typical commercially available material. These materials are considered representative of those available currently in the U.S. industry. Future experience could result in suggested revisions of these limiting values.

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<sup>4</sup> The number of tests are as suggested in the proposed ASTM test methods.

Prescriptive criteria, specified according to the “nominal” property values, provide a means of tighter control of the specified product. This is attractive for specifying modified bitumens, since so many materials are available, and collectively, their prescriptive properties cover a wide range of values. This approach to specifying prescriptive requirements as related to described property values is not novel, but has been used by the UEAtc [14,15]. A form of this approach has also been used at ASTM. However, in the case of ASTM, the specification usually indicates that the specified value of a given property be agreed upon between buyer and seller, with perhaps a minimum or maximum value being required.

**Table 6.** Prescriptive requirements for polymer-modified bituminous roofing membrane materials

Property	Prescriptive Requirement	ASTM Method <sup>a</sup>
Thickness	The average <sup>b</sup> thickness shall not be less than 5% of the nominal value as stated by the product manufacturer; the minimum shall be 0.040 in (1 mm).	Sec. 5
Load <sup>c</sup> max.	The average maximum load <sup>b</sup> shall not be less than 15% of the nominal value as stated by the product manufacturer.	Sec. 6
Elongation <sup>c</sup> at max. load	The average elongation at maximum load <sup>b</sup> shall not be less than 20% of the nominal value as described by the product manufacturer.	Sec. 6
Elongation <sup>c</sup> at break	The average elongation at break <sup>b</sup> shall not be less than 20% of the nominal value as described by the product manufacturer.	Sec. 6
Low-Temperature Flexibility	The low-temperature flexibility <sup>d</sup> shall not be more than 5 °F (3 °C) above the nominal the value as described by the product manufacturer; the maximum shall be 25 °F (−4 °C).	Sec. 11
Tear Resistance	The average tear resistance <sup>b</sup> shall not be less than 20% of the nominal value as described by the product manufacturer; the minimum shall be 30 lbf (130 N).	Sec. 8

<sup>a</sup> Method as given in the ASTM draft document [18]. As the present report was prepared, the ASTM draft was near to consensus agreement at the Subcommittee level. It has been widely debated, and few future changes are expected.

<sup>b</sup> Average of five measurements.

<sup>c</sup> In tension.

<sup>d</sup> No cracking for five specimens.

### 3.2 Suggested Interim Performance Criteria

This section of the report presents suggested interim performance criteria for modified bitumens. The list was based on reviewing the documents listed in section 2. Test methods referenced from ASTM and UEAtc are given in Appendix B and Appendix C, respectively.

The membrane and system characteristics for which criteria are suggested are:

- dimensional stability
- fire resistance
- flow resistance
- hail impact resistance
- moisture content and absorption
- pliability
- strain energy
- uplift resistance
- weathering resistance—heat exposure.

Some of the criteria, notably those on fire, flow, hail, strain energy, and uplift pertain to the modified bitumen as used in the roof system. The remainder are specific to the membrane material alone. It is realized that the list may be more extensive than DOD can conveniently apply to common use in guide specifications. One suggestion is that a core list of criteria be used in guide specifications, and that it be complemented, as necessary, on a case by case basis with other criteria.

### 3.2.1 Dimensional Stability

Requirement	The roof membrane shall not exhibit large irreversible dimensional change when exposed to temperatures encountered under normally expected service conditions.
Criterion	The linear dimensional change shall not be more than $\pm 1\%$ .
Test	ASTM proposed method of test, section 10 [18].
Commentary	Membrane materials may not be dimensionally stable, and undergo irreversible expansion or contraction in service. For example, shrinkage can result in stress in the membrane material and subsequent cracking, as well as loss of adhesion between components. Expansion can result in unwanted ridges and buckles that may crack or split, or be damaged by foot traffic and other user loads. Heat exposure is a major environmental factor which may result in irreversible dimensional change.

### 3.2.2 Fire Resistance

Requirement	The roofing system shall not pose an undue safety hazard when exposed to fire conditions.
Criterion	The system shall meet the requirements specified by the applicable building code concerning fire resistance (or local military regulations).
Test	The test shall be conducted using nationally recognized procedures such as those developed by ASTM, Underwriters Laboratories (UL), or Factory Mutual (FM).
Commentary	Test procedures for fire resistance, developed by ASTM, UL, or FM, have been widely used by the roofing industry, and are generally accepted by the construction industry [12].

### 3.2.3 Flow Resistance

Requirement	The roofing system shall resist slippage forces generated during service due to factors such as roof slope and elevated temperature exposure.
Criterion	No slippage (movement) shall occur, as tested.
Test	UEAtc M.O.A.T. No. 27, section 5.1.7 [13].
Commentary	<p>This test is intended for membrane systems installed with slopes. The test need not be conducted on roof systems that have the membrane mechanically anchored in place.</p> <p>Experience has shown that bituminous membrane materials may readily undergo slippage under certain conditions of use [21]. Slippage has been defined as "relative lateral movement of adjacent components of a built-up membrane" [22]. Slippage occurs mainly in roofing membranes on a slope, sometimes exposing the lower plies to the weather [22]. It is associated with the viscosity of the bitumen and other factors such as membrane surfacing and roof-top temperatures [21].</p>



### 3.2.4 Hail Impact Resistance

Requirement	The roofing system shall be capable of withstanding, without loss of waterproofing integrity, normally encountered hail impact loads due to environmental exposure.
Criterion	a) The roof membrane shall be able to withstand an impact of a 1.5 in (38 mm) diameter hailstone falling at a speed of 112 ft/s (34 m/s) without allowing water penetration [12].  or  b) The roof membrane shall withstand an impact of 22 lbf-ft (30 J) from a freely falling tup without allowing water penetration.
Tests	a) Hail impact—NBS hail resistance test, Building Science Series 23 and Building Science Series 55.  or  b) Falling Missile Impact—ASTM D 3746.
Commentary	<p>The hail impact criterion was first proposed for bituminous built-up membranes [12]. This test is of particular importance where the membrane is used in areas subjected to hail storms.</p> <p>Koontz [23] has conducted comparative testing of newer roofing membrane materials using both the hail impact and falling missile tests. He reported that comparable results were observed using the two procedures.</p> <p>In cases where it is questioned whether the membrane material is no longer watertight after the impact test, a watertightness test [24] may be conducted.</p>

### 3.2.5 Moisture Content and Absorption

Requirement	The moisture absorbed by the membrane in service shall not adversely affect its performance over the service life of the system.
Criteria	a) The moisture content of the membrane material shall not exceed 0.5 percent by mass.  b) The water absorption of the membrane shall not exceed 1 gram (for the given specimen size).
Tests	a) ASTM proposed method of test, section 8 [18].  b) ASTM proposed method of test, section 9 [18].
Commentary	Experience has shown that elevated moisture contents in bituminous membrane materials may have an adverse effect on both proper application of the membrane and also its performance in service [25]. The suggested criterion for water absorption was originally proposed in the MRCA Criteria [16] and the Canadian Standard [17] for modified bitumens.

### 3.2.6 Pliability

Requirement	The membrane material must be capable of being readily unrolled, flexed and bent without damage during application under normally expected environmental conditions.
Criteria	a) Low-temperature flexibility—The temperature at which cracking occurs shall not be less than the temperature at which the membrane material is to be installed. b) Unrolling at low-temperature—The membrane material shall be unrolled without cracking or tearing at 32 °F (0 °C).
Test	a) ASTM proposed method of test, section 11 [18]. b) UEAtc M.O.A.T. No. 27, section 5.4.3 [13].
Commentary	Membrane materials are delivered to the job site in roll form where they are unrolled during installation under temperature conditions which may reach 32 °F (0 °C) or lower. Low temperatures can result in embrittlement of the membrane material. Installation of the membrane should be avoided under low temperature conditions below which it may be embrittled and consequently damaged, e.g., cracking or splitting. This is of particular concern with base flashing materials whereby extremely sharp bends may be imposed on the materials. In general, APP-modified bitumens and SBS-modified bitumens have low-temperature flexibility points less than 23 °F (−4 °C) and 5 °F (−15 °C), respectively [14,15]. Under some circumstances, application of the membrane material might be conducted at air temperatures below the low-temperature flexibility point, provided adequate external heat can be provided to keep the material pliable.

### 3.2.7 Strain Energy

Requirement	The roof membrane shall withstand, without rupture, the normal stresses imposed from internal or external causes.
Criterion	The strain energy of the composite membrane material shall not be less than 3 lbf·in/in <sup>2</sup> (0.5 kN·m/m <sup>2</sup> ) in the weaker direction of the membrane when tested at 0 °F (−18 °C); in addition, the membrane shall remain watertight after elongation at 0 °F (−18 °C) to a percent at which the strain energy is equivalent to the criterion strain energy of 3 lbf·in/in <sup>2</sup> (0.5 kN·m/m <sup>2</sup> ).
Test	ASTM proposed method of test, section 6 [18].
Commentary	<p>This test should be conducted on the composite membrane. Only in cases where the modified bitumen material is installed as a single-ply membrane should the test be conducted on the single sheet alone.</p> <p>Certain membranes exhibit anisotropic behavior. Therefore, the results of tests in the weaker direction should apply. Excessive elongation of the membrane may cause cracking of the bitumen and loss of watertightness. Thus, a watertightness test is conducted at a percent elongation corresponding to the minimum strain energy.</p> <p>Strain energy is a measure of the ability of the membrane to resist energy loads before rupture. It is related to the toughness of the material, taking into consideration both strength and strain capacity of the membrane. It is determined in a tension test as the area under the load-elongation curve.</p> <p>The CIB/RILEM Committee [10] has indicated that the load-strain product offers an approach for evaluation of a membrane's ability to resist expansion generated by movement of the support below the membrane, but suggested that research is needed to provide the basis for use of the approach. Rossiter and Bentz [24] and Lee and Dupuis [26] have investigated the use of strain energy as a performance criterion for bituminous membranes. From their study, Lee and Dupuis proposed the use of strain energy as a means of having a safety factor for a membrane's ability to resist energy loads. Wells [27] recently reported on the preliminary results of an analytical study which indicated that a low strain energy value of 2 lbf·in/in<sup>2</sup> (0.4 kN·m/m<sup>2</sup>) may not be universal to all membrane materials. The criterion suggested above, 3 lbf·in/in<sup>2</sup> (0.5 kN·m/m<sup>2</sup>), was previously given as preliminary and that further research may provide a revised value of strain energy as a performance criterion [24]. Note that units of strain energy given herein account for gage length and width of the test specimen.</p>



### 3.2.8 Uplift Resistance

Requirement	The roof system shall withstand design uplift forces without adverse effect.
Criterion	The system shall meet the requirements specified by applicable building codes concerning uplift resistance (or local military regulations).
Test	The test shall be conducted using nationally recognized procedures developed by ASTM, Underwriters Laboratories (UL), or Factory Mutual.
Commentary	Test procedures for uplift resistance, developed by ASTM, UL, or FM, have been widely used by the roofing industry, and are generally accepted by the construction industry [12]. The requirement for uplift resistance will depend, among other factors, on the local wind conditions to which the roofing system will be exposed. Some local jurisdictions may have code requirements more stringent than national model codes because of local wind conditions.

### 3.2.9 Weathering Resistance—Heat Exposure

Requirement	The membrane shall be capable of sustaining exposure to normally encountered temperatures without significant loss of performance properties.
Criteria	<p>a) Load-elongation properties—the load-elongation properties shall not change by more than 15 percent from those determined for the unexposed material.</p> <p>b) Low-temperature flexibility—the low-temperature flexibility of the exposed membrane material shall not exceed 32 °F (0 °C).</p> <p>c) Strain energy—the strain energy of the membrane incorporating the heat aged modified sheet shall not be less than 3 lbf·in/in<sup>2</sup> (0.5 kN·m/m<sup>2</sup>).</p>
Test	ASTM proposed method of test, section 12 [18].
Commentary	<p>European experience has indicated that, for modified bitumens, oxidation in air is considered to be a major agent causing the deterioration of the membrane material [2,13-15,28]. This property is evaluated using a heat aging test in air. The ASTM draft list of test methods for modified bitumens has included a heat aging procedure and suggests determining load, elongation, strain energy, and low-temperature flexibility before and after exposure.</p> <p>The criteria suggested for these properties have had considerable use in the roofing industry. The criterion for changes of load-elongation properties was included in the MRCA criteria [16]. The criterion on low-temperature flexibility was included in the UEAtc documents [14,15]. A previous NBS (now NIST) study [23] has suggested that the strain energy of exposed membrane materials not be less than 3 lbf·in/in<sup>2</sup> (0.5 kN·m/m<sup>2</sup>).</p>

## 3.3 Needed Criteria for Future Development

The membrane requirements for which criteria are considered to be needed, but were not developed in the present report are:

- cyclic (substrate) movement resistance
- durability of protective surfacings
- puncture resistance
- seam strength
- slippage resistance of base flashings
- tear resistance
- water transmission resistance
- weather resistance (except heat exposure).

Because of the importance of having criteria for these requirements, an initial step in outlining performance criteria using the standard format was undertaken, but the criteria themselves were not proposed. With the exception of cyclic movement resistance, for each of the requirements listed above, the criteria are described as “not established.” In most cases, test methods upon which the

criteria may be based have been suggested. In a few cases, the test methods are also noted as “not established.” As previously indicated, a benefit in presenting this outline of needed criteria is to define the gaps for future criteria development and the needs for research to develop performance data. As future development of the criteria continues, the results should be incorporated into DOD guide specifications.

### 3.3.1 Cyclic Movement Resistance

- Requirement** The roofing membrane shall resist the movement of the membrane substrate encountered during normal service conditions without splitting, tearing, cracking, or undue deformation.
- Criterion** When tested, no loss of waterproofing through splits, cracks, tears, buckling, and similar defects shall occur in the membrane. In addition, total loss of adhesion of the membrane material to the substrate shall not occur.
- Test** UEAtc M.O.A.T. No. 27, section 5.1.8 [13].

**Commentary** The CIB/RILEM Committee has considered that the ability of roofing membranes to withstand expansion and contraction generated by cyclic movement of the membrane substrate is among the more important properties concerning membrane performance [10]. Factors influencing cyclic movement resistance include the amplitude and frequency of the cycle, and the temperature of the test. Characteristics of the polymer-modified bituminous roofing membrane materials which affect their performance in cyclic movements tests are the type of reinforcement and its location in the sheet, as well as the bitumen itself. The evaluation of the ability of modified bitumens to resist cyclic movement may allow the classification of these materials into categories depending upon the extent of expected movement in service [10].

The UEAtc evaluation procedure [13] in the test procedure allows for minor cracking and buckling (no loss of watertightness), or partial loss of adhesion to occur during the test. Guidance is given that such occurrence should be evaluated on an individual basis. This test is not conducted on loose-laid membranes.

This test for resistance to cyclic movement has received little attention in the U.S. roofing industry. Data are needed to support the suggested criterion and implement its use. It should be kept in mind that the suggested criterion comes from Europe (UEAtc General Directives), as have many of the modified bitumens on the U.S. market. The products of European origin may have undergone cyclic movement evaluation under the Agrément system in Europe.

### 3.3.2 Durability of Protective Surfacings

- Requirement** Factory-applied protective surfacings on polymer-modified bituminous roofing membrane materials shall provide protection to the membrane over the service life of the roof system.
- Criteria**
- a) Granular protection—not established.
  - b) Foil protection—not established.
- Tests**
- a) Granular protection—ASTM proposed method of test, section 15 [18].
  - b) Foil protection—CGSB method of test, section 7.2.6 [17].
- Commentary** Many of the modified bitumens have a factory applied surfacing to provide protection from ultraviolet radiation. The typical surfacings are roofing granules and metal foils. The surfacing should remain intact over the service life of the membrane to prevent premature deterioration. Loss of factory-applied protective surfacings in service could result in rapid deterioration of the membrane. The test procedure for foil protection was included in both the MRCA [16] and CGSB [17] documents. Of the two, only the CGSB standard had a requirement for granule embedment.



### 3.3.3 Puncture Resistance

**Requirement** The roofing system shall be capable of withstanding, without loss of integrity, the normally encountered static and dynamic puncture loads due to use and environmental exposure.

**Criteria** a) Static puncture—not established.  
b) Dynamic puncture—not established.

**Tests** a) Static puncture—UEAtc method of test, section 5.1.9.  
b) Dynamic puncture—French standard NF P 84-353.

**Commentary** The CIB/RILEM Committee [10] considered that puncture resistance is a key performance characteristic to be included in the evaluation of roofing membrane materials. Puncture loads may either penetrate the waterproofing integrity of the membrane, or result in undue deformation [13]. Puncture loads may arise from two sources: environmental exposure (e.g., falling tree limbs) and use of the roof (e.g., foot traffic).

Both static and dynamic puncture loads should be considered. Static loads are both relatively short term (e.g., foot traffic) and long term (e.g., ladders). Dynamic loads are of the impact type (e.g., dropping of tools). Two factors which influence puncture resistance are softening of the membrane material at elevated temperatures and the possible deformation of the membrane support.

The test procedures listed above have been recommended by the CIB/RILEM Committee. Criteria have not been established, but the Committee suggested that membranes may be classified in an increasing order of puncture resistance using the cited tests.

### 3.3.4 Seam Strength

**Requirement** Seams in single-ply membranes shall be watertight over the service life of the membrane.

**Criterion** Not established.

**Test** Not established.

**Commentary** The ability of seams in single-ply membranes to remain watertight is critical, since a delamination will result in a roof leak. Note that some modified bitumens are employed in single-ply roofing configurations. Evaluation of this property is not needed in cases where the modified bitumen is used in a multi-ply system.

Both the UEAtc general directives [13] and MRCA criteria [16] have included seam characterization using a lap-shear test. Recent investigations of the use of the lap-shear test for evaluating the quality of adhesive-bonded seams in rubber membranes indicated that the procedure is not sensitive to various application conditions expected to affect bond strength adversely [29]. Considering this finding, the use of the lap-shear test for evaluating seams of modified bitumens is not included in the criteria in the present report. It is considered that the applicability of this test method or an improved method needs to be established.

### 3.3.5 Slippage Resistance of Base Flashings

Requirement	When used as base flashing, the modified bitumen material must be capable of resisting creep and tearing forces generated under service conditions.
Criterion	Not established.
Test	ASTM proposed method of test, section 15 [18].
Commentary	In addition to their use as membrane materials, modified bitumens are also used as base flashings on vertical surfaces. The base flashing should remain in place without undue slippage and tearing at mechanical fasteners which may be used to secure the flashing in place. This property is temperature dependent. Elevated temperatures may soften polymer modified bitumens producing slippage, drippage, accelerated creep, and lowered resistance to tearing. Research is needed to provide the data to establish the criterion.

### 3.3.6 Tear Resistance

Requirement	The membrane material shall have sufficient strength to allow handling without damage under normal installation conditions, and withstand normally expected tear loads encountered in service.
Criterion	Not established.
Test	Not established; suggested tests are the ASTM proposed method of test, section 7 [18], and the UEAtc procedure [13].
Commentary	<p>Roof systems are installed under a variety of environmental conditions using extensive manual labor that can impart tear loads through tugging and pulling during application. Membrane materials with low tear resistance may not adequately survive the rigors of installation and be easily damaged during handling on site.</p> <p>Membranes, particularly those partially attached, may be subjected in service to tear forces because of factors such as wind flutter, shrinkage, and thermal movement.</p> <p>The CIB/RILEM Subcommittee has recommended that the UEAtc procedure be used to evaluate this property. However, no criterion was suggested. Measurements and analysis of tear forces in service may be needed to help provide a basis for the criterion.</p>

### 3.3.7 Resistance to Water Transmission

Requirement	The roofing membrane shall prevent the penetration of water through the roofing system.
Criterion	The membrane shall be watertight, as tested.
Test	Not established; suggested tests include those in the UEAtc [13], MRCA [16], and CGSB [17] documents.
Commentary	<p>The ability of the membrane to keep the roof watertight is its basic function. Unwanted pinholes may be incorporated into the membrane material during manufacture and provide pathways for water transmission into the system. This criterion is intended to evaluate this property.</p> <p>Since pinholes may expand upon heating and possibly lower the resistance of the membrane material to prevent water transmission, it may be of interest to evaluate this property after subjecting the membrane material to temperatures comparable to those encountered during application to its substrate.</p> <p>A test procedure is not suggested at this time from those available, because of the subtle differences which exist between those listed above. For example, a water column (head of water) test is normally used. However, the height of the column differs in each of the cited tests. In addition, the utility of a water column test for detecting pinhole faults in membranes has been questioned [30].</p>



### 3.3.8 Weathering Resistance (except heat exposure)

Requirement	The membrane material shall be capable of sustaining exposure to normally encountered environmental agents including ultraviolet (UV) radiation, moisture, chemical pollutants, and fungus without significant loss of performance properties.
Criteria	<ul style="list-style-type: none"><li>a) UV exposure—not established.</li><li>b) Moisture exposure—not established.</li><li>c) Chemical exposure—not established.</li><li>d) Fungus growth—not established.</li></ul>
Tests	<ul style="list-style-type: none"><li>a) UV exposure—not established.</li><li>b) Moisture exposure—not established.</li><li>c) Chemical exposure—not established.</li><li>d) Fungus growth—not established.</li></ul>
Commentary	<p>During service, roofing membrane systems are subjected to a wide variety of environmental agents such as temperature, ultraviolet radiation, moisture, gases, and chemical pollutants which can cause deterioration of performance properties. Research is needed to develop predictive methodologies for evaluating the long-term serviceability of membrane materials [11]. At present, the ASTM draft list of methods includes a UV resistance test. Because experience in applying the test to modified bitumens is limited, the ASTM draft proposal on UV resistance is not included in the present document.</p>

When considering weathering tests, the European experience with modified bitumens offers some approaches that may be considered in performance tests:

a) *ultraviolet radiation*. The upper surfaces of modified bitumens may or may not be left exposed depending upon the membrane system. In the UEAtc system [14,15], consideration of the potential deleterious effects of UV radiation is considered necessary in cases where the top ply of the membrane is directly exposed to solar radiation. It is noted that SBS membrane materials normally have a protective covering; whereas APP membrane materials are used, at times, directly exposed to the sun without a covering.

The UEAtc documents [14,15] consider that the resistance to UV radiation is deemed satisfactory if the membrane:

- 1) is used under aggregate surfacing, or
- 2) contains its own protection (i.e., granules or foil) incorporated during manufacture.

In these cases, the UEAtc documents do not contain requirements for conducting UV tests.

b) *moisture*. Moisture is considered to be among the key environmental factors causing deterioration of building materials. European experience with modified bitumens has indicated that water has not, in general, adversely affected the performance characteristics of the modified bitumens, provided that the reinforcement is sufficiently impregnated and coated. The UEAtc documents [14,15] indicated that testing of modified bitumens is carried out only in cases where concern exists that water could have an adverse effect on an individual product. Key changes in performance characteristics of the membrane material considered to be affected are loss of:

- 1) low-temperature flexibility,
- 2) bitumen adhesion to the reinforcement, and
- 3) granule embedment.

c) *chemical agents*. Depending upon building use and location, a roofing system may be subjected to chemical agents such as industrial oils, and environmental pollutants which could adversely affect performance. This property has received little attention in Europe. For example, the UEAtc special directives [14,15] have no requirements for evaluating the resistance to chemical agents. The MRCA document [16] suggests that, when chemical resistance is of concern, the membrane manufacturer be asked to provide a list of agents that may be harmful.

d) *fungal growth*. Experience has shown that certain environmental conditions may promote the growth of fungus on the roof surface. In cases where concern exists that fungal growth could occur, the resistance of the membrane (or its protective surfacing) should be evaluated. The European documents do not address this criterion [14,15]. Procedures need to be developed.

#### 4. SUMMARY AND CONCLUSIONS

This report has presented the results of a study to develop interim criteria for the selection of polymer-modified bituminous roofing membrane materials. The criteria are intended for use by the construction agencies of the Department of Defense in specifying modified bitumens until voluntary consensus standards are developed in the United States.

The criteria were suggested on the basis of performance considerations for low-sloped roofing. Thus, the suggested interim criteria were generally presented using a performance criteria format. This format was first developed in the early 1970s for bituminous built-up membranes. Although the various products available to the U.S. roofing industry may use different polymer modifiers and reinforcements, the suggested criteria are not divided into classifications based on modifier or reinforcement. Future expansion of the performance concept to modified bitumens may allow their classification into categories concerning performance properties, e.g., low or high resistance to puncture or cyclic movement. Such classification could reflect differences between modifiers or reinforcements.

Prescriptive criteria for five membrane characteristics were used to complement the suggested performance criteria. These characteristics were thickness, tensile load, tensile elongation, low-temperature flexibility, and tear resistance. The approach of using complementary prescriptive criteria was taken to incorporate into the performance criteria test methods which can be relatively rapidly performed for characterization or identification of the membrane material. Table 7 provides a summary of the prescriptive and performance criteria and tests suggested in the study.

Table 7. Summary of suggested prescriptive and performance criteria for modified bitumens

Requirement	Test Method	Criterion
Thickness	ASTM draft, Sec. 5	not <5% of the nominal value, 40 mil (1 mm) minimum
Load, max.	ASTM draft, Sec. 6	not <15% of the nominal value
Elongation (max. load)	ASTM draft, Sec. 6	not <20% of the nominal value
Elongation (break)	ASTM draft, Sec. 6	not <20% of the nominal value
Low-Temperature Flexibility	ASTM draft, Sec. 11	not >5 °F (3 °C) of nominal, 25 °F (-4 °C) maximum
Tear Resistance	ASTM draft, Sec. 7	not <20% of the nominal value 30 lbf (130 N) minimum
Dimensional Stability	ASTM draft, Sec. 10	max. change, ±1%
Fire Resistance	ASTM, UL or FM test	conform to applicable code
Flow Resistance	UEAtc No. 27 Sec. 5.1.7	no slippage
Hail Impact	NBS BSS 55 or ASTM D 3746	1.5 in (38 mm) hail stone at 112 ft/s (34 m/s) without water penetration 22 lbf-ft (30 J) without water penetration
Moisture Absorp.	ASTM draft, Sec. 9	1 gram (per specimen), max.
Moisture Content	ASTM draft, Sec. 8	0.5% by mass, max.
Pliability	a) ASTM draft, Sec. 11 b) UEAtc No. 27 Sec. 5.4.3.	no cracking at temperatures of application no cracking or tearing when unrolled at 32 °F (0 °C)
Strain Energy	ASTM draft, Sec. 6	not less than 3 lbf-in/in <sup>2</sup> (0.5 kN-m/m <sup>2</sup> )
Uplift	ASTM, UL or FM test	conform to applicable code
Weather Resist. Heat Exposure	ASTM draft, Sec. 12	15% max. change of load-elongation; low-temperature flexibility not to exceed 32 °F (0 °C); strain energy not less than 3 lbf-in/in <sup>2</sup> (0.5 kN-m/m <sup>2</sup> ).



In addition to the criteria in table 7, other membrane requirements were listed for future development of criteria, but criteria were not suggested at the present. The criteria needed for future development were provided in performance criteria format to indicate the gaps in the knowledge base. Table 8 lists the membrane requirements for which criteria were not proposed. Lack of an acceptable database in the existing standards precluded suggesting completed criteria for these requirements at this time. Nevertheless, it was considered beneficial to present the needed criteria as a first step toward directing future research for standards development concerning the modified bitumens.

In concluding the study, it is recommended that:

- 1) the criteria in table 7 be incorporated into guide specifications developed by DOD for use of modified bitumens, and
- 2) research continue to address completion of the proposed criteria given in table 8.

**Table 8.** Summary of modified bitumens for which criteria have not been proposed

Requirement	Test Method	Criterion
Cyclic Movement <sup>a</sup>	UEAtc No. 27	no tears, cracks, or wrinkles: no total loss of adhesion
Durability, Granules	ASTM draft, Sec. 15	not established
Durability, Foils	CGSB, Sec. 7.2.6	not established
Puncture, (static)	UEAtc No. 27, Sec. 5.1.9	not established
Puncture, (dynamic)	French Std., NF P 84-353	not established
Seam Strength	not established	not established
Slippage of Base Flashing	ASTM draft, Sec. 15	not established
Tear Resistance	not established	not established
Water Transmission	not established	the membrane shall be watertight as tested
Weathering (UV)	not established	not established
Weathering (moisture)	not established	not established
Weathering (chemical)	not established	not established
Weathering (fungus)	not established	not established

<sup>a</sup> Although a criterion is proposed for this requirement, a database is lacking at this time for implementation of the suggested criterion.

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## APPENDIX A. PRELIMINARY DATA ON TYPICAL POLYMER-MODIFIED BITUMINOUS ROOFING MEMBRANE MATERIALS

### A.1 INTRODUCTION

During this study, limited laboratory testing was conducted on five typical modified bitumens that were commercially available in the U.S. roofing industry. The five products are described in table A1. As is evident, two of the membrane samples were APP-modified, and two were SBS-modified. The fifth sample was a self-adhering membrane material that had an SBS-type modifier.

The tests were conducted to compare the proposed interim criteria with properties of typical commercially-available modified membrane samples. Because the scope of the study was to suggest criteria for selecting polymer-modified bitumens based on a review of existing standards and related documents, the testing conducted on the membrane samples was limited. For example, load-elongation tests were only conducted on the sheets in their transverse (or cross-machine) direction.

**Table A1.** Modified bitumen samples included in the study

Sample No.	Membrane Material
1.	Atactic-propylene (APP) modified; no surfacing
2.	Atactic-propylene (APP) modified; no surfacing
3.	Styrene-butadiene-styrene (SBS) modified; surfacing consisting of white granules
4.	Styrene-butadiene-styrene (SBS) modified; no surfacing; this sheet is only used as a base ply in a 2-ply membrane
5.	Styrene-butadiene-styrene (SBS) modified; self-adhering material with a surfacing consisting of a white polymeric film

This Appendix presents the results of the limited tests (tables A2–A13). The membrane characteristics examined were thickness, tensile strength, tensile elongation, low-temperature flexibility, tear resistance, dimensional stability, moisture content, and strain energy. Each of these tests was conducted according to the method cited in table 7 of the main body of the report. The data were used in support of the prescriptive criteria suggested in table 7. In addition, heat and UV exposure tests were conducted according to the proposed ASTM methods.

## A.2 RESULTS

### A.2.1 Thickness

The results of the thickness are given in table A2. The membrane materials ranged from as thin as 0.04 in (1 mm) to as thick as 0.16 in (4 mm). For any specimen, the variation in measured thickness did not exceed 4 percent. This reflects the automatic control that modern roofing plants use to monitor and adjust the thickness of the factory-fabricated membrane material. Based on these results, it is suggested in the criteria (table 6) that the average thickness of a product not be less than 5 percent of the nominal value stated by the manufacturer.

Table A2. Thickness of the test specimens<sup>a</sup>

Sample No.	Thickness				COV <sup>b</sup> %
	in		mm		
	range	av	range	av	
1.	0.153–0.160	0.157	3.89–4.06	3.99	1.7
2.	0.146–0.156	0.153	3.71–3.96	3.89	2.7
3.	0.156–0.158	0.156	3.96–4.01	3.97	0.6
4.	0.087–0.093	0.090	2.21–2.36	2.28	3.5
5.	0.042–0.046	0.044	1.07–1.17	1.12	4.0

<sup>a</sup> Average of five measurements, ASTM draft, Sec. 5.

<sup>b</sup> COV indicates coefficient of variation.

### A.2.2 Tensile Strength

Table A3 presents the tensile strength (load) results for tests conducted at both 73 °F (23 °C) and 0 °F (–18 °C). For these tests, “dog-bone” specimens were used instead of strip specimens as suggested in the ASTM draft [18]. The results indicated that, as was expected [24], the materials were stronger at the lower temperature. At 0 °F (–18 °C), the strength ranged from 39 to 218 lbf/in (6.9 to 38 kN/m). This finding is consistent with published data on the load-elongation properties of the modified bitumens that indicate a wide range of strength [24,26].

Note that most of the samples in table A3 had coefficients of variation of 10 percent or less. For one measurement, the variation was 14 percent. These results were used to support the suggested load criterion that the average value not be less than 15 percent of the nominal value stated by the manufacturer.

Table A3. Tensile strength of the specimens tested at 73 and 0 °F (23 and –18 °C) before laboratory exposure<sup>a</sup>

Sample No.		Load, max.				COV <sup>b</sup> %
		lbf/in		kN/mm		
		range	av	range	av	
73 °F (23 °C)	1.	106–126	113 <sup>c</sup>	19 –22	20 <sup>c</sup>	8.4
	2.	54– 63	60	9.4–11	11	5.4
	3.	48– 58	54	8.4–10	9.5	7.9
	4.	11– 16	14	1.9– 2.8	2.3	14
	5.	56– 60	58	9.8–11	10	3.2
0 °F (–18 °C)	1.	193–240	218	34 –42	38	10
	2.	106–128	114	19 –22	20	7.4
	3.	70– 90	80	12 –16	14	11
	4.	37– 42	39	6.5– 7.4	6.9	5.2
	5. <sup>d</sup>	67– 77	74	12 –14	13	5.2

<sup>a</sup> Average of five measurements (unless otherwise indicated), ASTM draft, Sec. 6; tests conducted on the transverse direction of the sheet.

<sup>b</sup> COV indicates coefficient of variation.

<sup>c</sup> Average of four measurements.

<sup>d</sup> Specimen did not break; test terminated at 50 percent elongation due to lack of space in the cold chamber.



### A.2.3 Elongation

Table A4 presents the percent elongation results for tests conducted at both room temperature and 0 °F (−18 °C). For samples 2, 3, and 4, the elongation decreased as the temperature decreased. Sample 1 showed little variation of elongation for the two test temperatures. This observation was not surprising, as it was noted for a modified bitumen in a previous study [24]. Sample 5 could not be extended to its maximum at 0 °F (−18 °C) because of lack of extension space in the cold chamber. In this case, specimen elongation had reached 50 percent, when the test was terminated.

**Table A4.** Elongation of the specimens under tensile load tested at 73 and 0 °F (23 and −18 °C) before laboratory exposure<sup>a</sup>

Sample No.	Elongation, %					COV <sup>b</sup> %
	At Maximum Load range	av	COV <sup>b</sup> %	At Specimen Break range	av	
73 °F (23 °C)	---	---	---	1.8– 2.2	2.0 <sup>d</sup>	9.9
	34 – 40	37	7.1	38 – 46	42	9.7
	---	---	---	33 – 47	39	14
	1.5– 2.6	2.0 <sup>d</sup>	2.2	9.1– 9.9	9.6 <sup>d</sup>	3.8
	97 –177	139	29	136 –177	157	12
0 °F (−18 °C)	---	---	---	1.9– 3.1	2.3	23
	6.6– 12	8.0	42	7.9– 14	12	22
	---	---	---	20 – 34	29	19
	---	---	---	1.8– 2.7	2.2	17
	---	---	---	NA <sup>e</sup>	50 <sup>f</sup>	NA <sup>e</sup>

<sup>a</sup> Average of five measurements (unless otherwise indicated), ASTM draft, Sec. 6; tests conducted on the transverse direction of the sheet.

<sup>b</sup> COV indicates coefficient of variation.

<sup>c</sup> The dash lines indicate that the maximum load occurred essentially (within 10%) at the end of the test.

<sup>d</sup> Average of four measurements.

<sup>e</sup> Not applicable; specimen did not break; test terminated at 50 percent elongation due to lack of space in the cold chamber.

<sup>f</sup> All tests terminated at 50 percent elongation.

As is evident from table A4, depending on the temperature, the elongations of the five samples varied considerably, ranging from about 2 percent (Samples 2 and 4) to over 150 percent (Sample 5) at break. The greatest coefficient of variation was 23 percent. Consistent with this finding, it was suggested (table 6) that the average measured elongation not be less than 20 percent of the nominal value stated by the manufacturer.

### A.2.4 Low-Temperature Flexibility

The values of low-temperature flexibility determined for the test samples are given in table A5. They ranged from 23 °F (−5 °C) to less than −30 °F (−34 °C). The APP-modified samples (Nos. 1 and 2) had higher values than the SBS-modified samples (Nos. 3–5). The results were consistent with literature citations that low-temperature flexibility points of APP and SBS materials are normally less than 25 °F (−4 °C) and 5 °F (−15 °C), respectively.

**Table A5.** Low-temperature flexibility of the test specimens before laboratory exposure<sup>a</sup>

Sample No.	Lowest Temperature at Which Cracking Did Not Occur	
	°F	°C
1.	23	−5
2.	8	−13
3.	−2	−19
4.	−23	−30
5.	< −30 <sup>b</sup>	< −34 <sup>b</sup>

<sup>a</sup> Test of five specimens, ASTM draft, Sec. 11; the low-temperature flexibility value was that temperature at which none of the five specimens cracked.

<sup>b</sup> Test was not conducted below this temperature.

### A.2.5 Tear Resistance

The results of the tear resistance tests are given in table A6. As was the case for tensile strength, the maximum tear load showed a wide variation between the five materials, ranging from 32 to 144 lbf (142 to 639 N). The maximum coefficient of variation (19%) was observed for Sample 4; the remaining 4 samples had coefficients of variation of 10 percent or less. The suggested criterion (table 6) is that the average tear resistance not be less than 20 percent of the stated nominal value.

Table A6. Tear resistance of the test specimens<sup>a</sup>

Sample No.	Load, max.		N		COV <sup>b</sup> %
	range	lbf av	range	av	
1.	131–168	144	584–746	639	10
2.	92–104	96	407–460	428	5
3.	82– 98	87	365–436	386	8
4.	24– 41	32	108–184	142	19
5.	72– 78	76	320–349	338	4

<sup>a</sup> Average of five specimens, ASTM draft, Sec. 7.

### A.2.6 Dimensional Stability

When heated at 176 °F (80 °C) for 24 hours, the test samples generally showed little dimensional change (table A7). Specifically, Samples 2 and 5 exhibited a change in the length (longitudinal direction of sheet) of 1 percent, but no change in width. The other three samples had no measurable dimensional change. Note that the data for this characteristic are limited, having been conducted only on one specimen of each sample. Nevertheless, the results are consistent with the suggested criterion that the dimensional change on heating not exceed 1 percent (table 7).

Table A7. Dimensional stability of the test specimens<sup>a</sup>

Sample No.	Dimensional Change, % <sup>b</sup>	
	length	width
1.	0	0
2.	1	0
3.	0	0
4.	0	0
5.	1	0

<sup>a</sup> Average of five measurements on one specimen, ASTM draft, Sec. 10.

<sup>b</sup> The variation was negligible for the tests conducted, and is not reported.

## A.2.7 Moisture Content

Moisture contents for the five samples were found to be 0.3 percent by mass or less (table A8). Only one determination was made for each membrane sample. The limited data are consistent with the suggested criterion that moisture content not be greater than 0.5 percent by mass (table 7).

Table A8. Moisture content of the test specimens<sup>a</sup>

Sample No.	Moisture Content by Mass, % <sup>b</sup>
1.	0
2.	0.3
3.	0.1
4.	0.2
5.	0

<sup>a</sup> One measurement only per specimen, ASTM draft, Sec. 8.

## A.2.8 Strain Energy

The results of the strain energy determinations at both room temperature and 0 °F (–18 °C) are given in table A9. The suggested criterion for strain energy is that it not be less than 3 lbf·in/in<sup>2</sup> (0.5 kN·m/m<sup>2</sup>) when the membrane material is tested at 0 °F (–18 °C) in its weaker direction. This criterion value was selected based on recommendations for bituminous built-up membranes [24]. The value for the criterion was also the minimum suggested in the MRCA performance criteria for modified bitumens [16].

Table A9. Strain energy per unit gage length of the specimens tested at 73 and 0 °F (23 and –18 °C) before laboratory exposure<sup>a</sup>

Sample No.	Strain Energy, lbf·in/in <sup>2</sup> (N·m/m <sup>2</sup> )					
	At Maximum Load		COV <sup>b</sup>	At Specimen Break		COV <sup>b</sup>
	range	av	%	range	av	%
73 °F (23 °C)	---	---	---	1.1 – 1.5 (0.19– 0.26)	1.3 (0.23)	14
	15 –21 (2.6 – 3.7)	18 (3.2)	13	17 –25 (3.0 – 4.4)	21 (3.7)	15
	---	---	---	11 –19 (1.9 – 3.3)	15 (2.6)	20
	0.16– 0.26 (0.03– 0.05)	0.21 <sup>d</sup> (0.04)	21	0.89– 1.1 (0.16– 0.19)	0.98 <sup>d</sup> (0.17)	9.0
	41 –87 (7.2 –15)	67 (12)	34	63 –87 (11 –15)	76 (13)	15
0 °F (–18 °C)	---	---	---	2.2 – 4.6 (0.39 – 0.81)	3.0 (0.53)	36
	2.9 –12 (0.51– 2.1)	7.5 (1.3)	44	8.3 –14 (1.5 – 2.5)	11 (1.9)	23
	---	---	---	11 –29 (1.9 – 5.1)	18 (3.2)	27
	---	---	---	0.42– 0.64 (0.07– 0.11)	0.55 (0.10)	18
	---	---	---	28 –32 (4.9 – 5.6)	30 <sup>e</sup> (5.3)	1.1

<sup>a</sup> Average of five measurements (unless otherwise indicated), ASTM draft, Sec. 6; tests conducted on the transverse direction of the sheet.

<sup>b</sup> COV indicates coefficient of variation.

<sup>c</sup> The dash lines indicate that the maximum load occurred essentially (within 10%) at the end of the test.

<sup>d</sup> Average of four measurements.

<sup>e</sup> Specimen did not break; test terminated at 50 percent elongation due to lack of space in the cold chamber.



The data in table A9 indicate that four samples (Nos. 1–3, 5) have values of strain energy that meet or exceed the suggested minimum. Sample 4 has a strain energy at 0 °F (–18 °C) which is less than the suggested criterion. This product is normally used in service in conjunction with another ply of modified bitumen, and for this reason, should be tested as a composite membrane material.

### A.2.9 Heat and UV Exposure Tests

The results of the heat and UV exposure tests, conducted according to the procedure given in the ASTM draft [18], are presented in tables A10–A13, and illustrated in figures A1–A4. Although the results varied for the different membrane materials, in many cases, only slight changes (<15%) in the materials' tensile strength, elongation, low-temperature flexibility, and strain energy were found as compared to those property values for the unexposed samples.

Some of the major changes noted for each material are as follows:

- Sample 1:* a decrease of 20 percent in tensile strength due to UV exposure  
an increase in low-temperature flexibility from 23 °F (–5 °C) to slightly less than 40 °F (4 °C) upon heat and UV exposure
- Sample 2:* a decrease in elongation of about 60 percent due to heat and UV exposure, which accounted for a decrease in total strain energy of about 68 percent  
an increase in low-temperature flexibility from 8 °F (–13 °C) to 24 °F (–4 °C) due to heat exposure; this test could not be conducted on the UV-exposed specimens because the exposure resulted in cracking of the specimen surface
- Sample 3:* an increase in tensile strength of about 40 percent and a drop in elongation of about 28 percent due to UV exposure; the result was the effect on strain energy was a slight increase
- Sample 4:* an increase in low-temperature flexibility from –23 °F (–31 °C) to 32 °F (0 °C) upon UV exposure
- Sample 5:* changes in elongation could not be determined because the sample could not be extended beyond 50 percent in the cold chamber used during the tests  
a decrease in tensile strength of about 49 percent due to heat exposure; this resulted in a comparable decrease in total strain energy

**Table A10.** Tensile strength of the specimens tested at 0 °F (–18 °C) after laboratory exposure<sup>a</sup>

Load, max.						
Sample No.	lbf/in		kN/m		COV <sup>b</sup> %	
	range	av	range	av		
Heat	1.	210–245	231	37 –43	41	6.4
	2.	113–126	119	20 –22	21	3.9
	3.	82– 91	88	14 –16	15	5.0
	4.	42– 47	45	7.4– 8.2	7.9	4.0
	5. <sup>c</sup>	37– 39	38	6.5– 6.8	6.7	2.1
UV	1.	155–192	173	27 –34	30	10
	2.	87– 99	93	15 –17	16	5.2
	3.	101–136	114	18 –24	20	11
	4.	38– 42	41	6.7– 7.4	7.2	3.9
	5. <sup>c</sup>	57– 76	69	10 –13	12	11

<sup>a</sup> Average of five measurements, ASTM draft, Sec. 5.

<sup>b</sup> COV indicates coefficient of variation.

<sup>c</sup> Specimen did not break; test terminated at 50 percent elongation due to lack of space in the cold chamber.

**Table A11.** Elongation of the specimens under tensile load tested at 0 °F (– 18 °C) after laboratory exposure<sup>a</sup>

Sample No.	Elongation, %					
	At Maximum Load range	av	COV <sup>b</sup> %	At Specimen Break range	av	COV <sup>b</sup> %
Heat	1.	--- <sup>c</sup>	--- <sup>c</sup>	2.0–2.6	2.4	9.0
	2.	3.0–3.5	3.4	4.0–4.2	4.1	2.0
	3.	---	---	22 –30	26	13
	4.	---	---	1.9–2.6	2.4	12
	5.	---	---	NA <sup>d</sup>	50 <sup>e</sup>	NA <sup>d</sup>
UV	1.	---	---	1.2–3.0	2.1	32
	2.	1.8–2.2	2.1	3.6–5.9	4.7	23
	3.	---	---	11 –26	21	28
	4.	---	---	1.3–3.3	2.7	30
	5. <sup>f</sup>	---	---	NA <sup>d</sup>	50 <sup>e</sup>	NA <sup>d</sup>

<sup>a</sup> Average of five measurements (unless otherwise indicated), ASTM draft, Sec. 6; tests conducted on the transverse direction of the sheet.

<sup>b</sup> COV indicates coefficient of variation.

<sup>c</sup> The dash lines indicate that the maximum load occurred essentially (within 10%) at the end of the test.

<sup>d</sup> Not applicable; specimen did not break; test terminated at 50 percent elongation due to lack of space in the cold chamber.

<sup>e</sup> All tests terminated at 50 percent elongation.

<sup>f</sup> Average of four measurements.

**Table A12.** Low-temperature flexibility of the test specimens after laboratory exposure<sup>a</sup>

Sample No.	Lowest Temperature at Which Cracking Did Not Occur	
	°F	°C
Heat	1.	39
	2.	24
	3.	2
	4.	–23
	5.	<–30 <sup>b</sup>
UV	1.	38
	2.	--- <sup>c</sup>
	3.	–2
	4.	32
	5.	<–30 <sup>b</sup>

<sup>a</sup> Test of five specimens, ASTM draft, Sec. 11.

<sup>b</sup> Test was not conducted below this temperature.

<sup>c</sup> Specimens were severely cracked on the surface after the UV exposure and consequently could not be tested by a procedure that has cracking as the test criterion.

Table A13. Strain energy per unit gage length of the specimens tested at 0 °F (– 18 °C) after laboratory exposure<sup>a</sup>

Strain Energy, lbf·in/in <sup>2</sup> (N·m/m <sup>2</sup> )							
Sample No.	At Maximum Load		COV <sup>b</sup> %	At Specimen Break		COV <sup>b</sup> %	
	range	av		range	av		
Heat	1.	--- <sup>c</sup>	--- <sup>c</sup>	2.4 – 3.9 (0.42– 0.68)	3.2 (0.56)	17	
	2.	2.7–3.3 (0.47–0.58)	3.1 (0.54)	8.0	3.5–3.9 (0.61–0.68)	3.7 (0.65)	4.3
	3.	---	---	---	16–22 (2.8–3.9)	19 (3.3)	16
	4.	---	---	---	0.54–0.86 (0.09–0.15)	0.74 (0.13)	17
	5.	---	---	---	16–17 (2.8–3.0)	16 <sup>d</sup> (2.8)	2.3
UV	1.	---	---	---	1.0–3.4 (0.18–0.60)	2.4 (0.42)	38
	2.	1.0–1.5 (0.18–0.26)	1.3 (0.23)	17	2.4–4.6 (0.42–0.81)	3.4 (0.60)	28
	3.	---	---	---	10–28 (1.8–4.9)	20 (3.5)	34
	4.	---	---	---	0.33–1.0 (0.06–0.18)	0.77 (0.13)	34
	5. <sup>e</sup>	---	---	---	27–31 (4.7–5.4)	29 <sup>d</sup> (5.1)	6.5

<sup>a</sup> Average of five measurements (unless otherwise indicated), ASTM draft, Sec. 6; tests conducted on the transverse direction of the sheet.

<sup>b</sup> COV indicates coefficient of variation.

<sup>c</sup> The dash lines indicate that the maximum load occurred essentially (within 10%) at the end of the test, and the strain energy was taken only as that at break.

<sup>d</sup> Specimen did not break; test terminated at 50 percent elongation due to lack of space in the cold chamber.

<sup>e</sup> Average of four measurements.



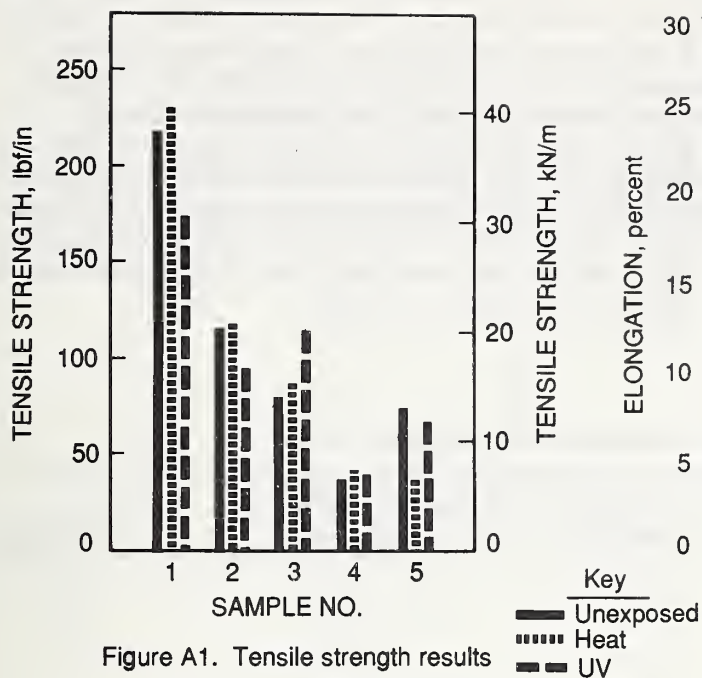


Figure A1. Tensile strength results

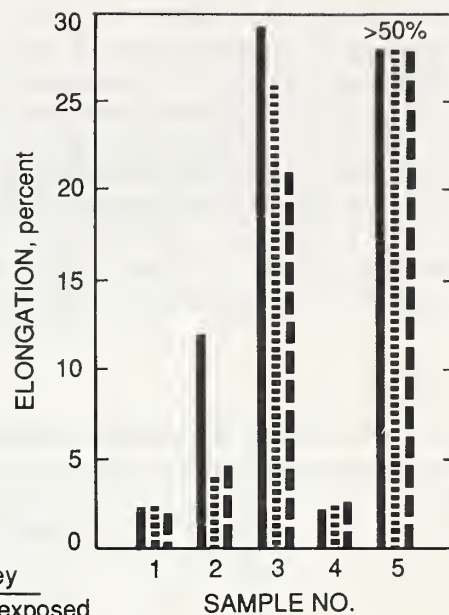


Figure A2. Elongation results

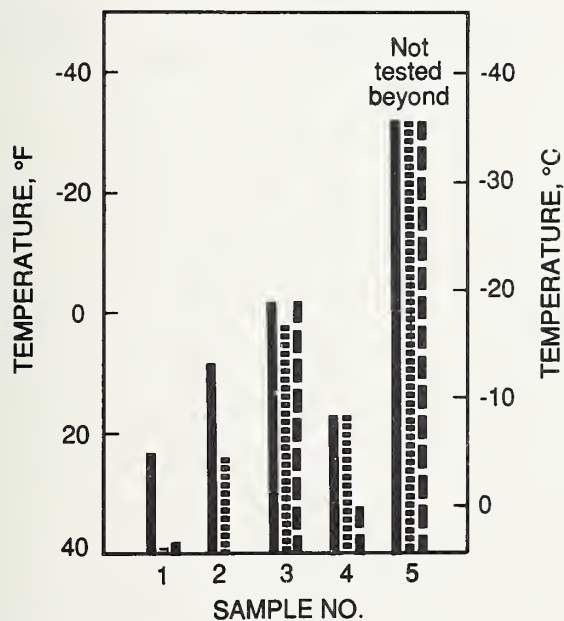


Figure A3. Low-temperature flexibility results

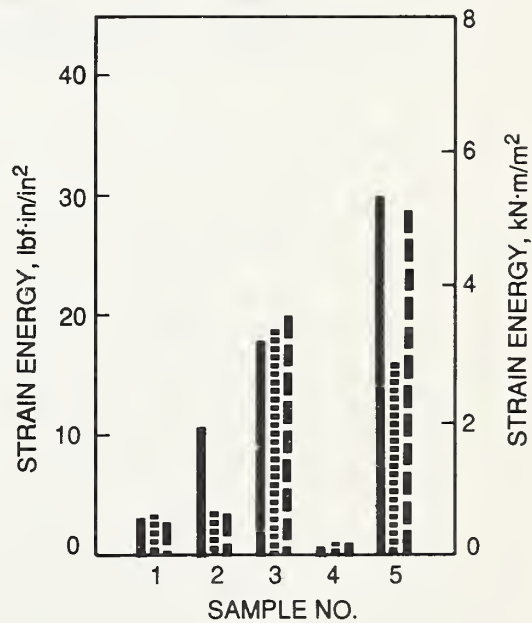


Figure A4. Strain energy results

Table A14 gives a comparison of the results of membrane materials in the heat exposure test to the criteria for behavior upon heat exposure, as suggested in section 3.2.9. It is evident that only one of the five materials meet the suggested criteria, although Sample 4 had a strain energy less than 3 lbf·in/in<sup>2</sup> (0.5 kN·m/m<sup>2</sup>) before heat exposure. Nevertheless, this observation is not considered a limitation to use of the proposed criteria on an interim preliminary basis. The criteria have been taken from existing documents (consistent with the objective of the study) which have achieved acceptance by the roofing industry in the area of the world where they were developed. The criteria for tensile strength and elongation were proposed by the MRCA [16]. The criterion for low-temperature flexibility was promulgated by the European Board of Agrément [14,15].

No criteria were suggested for the UV exposure tests. The ASTM draft suggests that load, elongation, low-temperature flexibility, and strain energy be measured before and after exposure [18]. However, data relating the suggested ASTM UV test procedure to resistance to exposure to solar radiation have not been developed. In general, experience with UV testing of modified bitumens has been limited, and a basis does not exist on which to suggest criteria. Research is needed to fill this gap and develop the basis for suggesting UV exposure criteria.

**Table A14. Test results of the heat-exposed samples compared with the suggested criteria**

Sample No.	Conformance to the Suggested Criterion			
	Tensile	Elongation	Low-Temp. Flex.	Strain Energy
1.	Yes	Yes	No	Yes
2.	Yes	No	Yes	Yes
3.	Yes	Yes	Yes	Yes
4.	Yes	Yes	Yes	No
5.	No	NA	Yes	Yes

## **APPENDIX B. ASTM DRAFT TEST PROCEDURES CITED IN THE CRITERIA**

This appendix reproduces the ASTM draft test procedures for modified bitumens that are cited in the main text of the report (table 7). The procedures are reproduced with the permission of the Chairman of ASTM Committee D08. As the present report was nearing completion, the ASTM draft procedures had been thoroughly debated by Subcommittee D08.04, and were close to acceptance in a ballot of April 1988. Although it is anticipated that they will eventually be approved by ASTM D08 without major changes, the reader is cautioned to check with D08 for the latest version of the list of procedures.



PROPOSED STANDARD TEST METHODS FOR SAMPLING AND TESTING  
MODIFIED BITUMINOUS SHEET MATERIALS USED IN ROOFING AND  
WATERPROOFING

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1. Scope

1.1 These test methods cover procedures for sampling and testing prefabricated, reinforced, polymer modified bituminous sheet materials designed for single or multiple ply application in roofing and waterproofing membranes. These products consist of a core material covered on either one or both sides with polymer modified bitumen. These products may employ various surfacing materials on one side.

1.2 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety aspects associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.3 These methods appear in the following order.

	Section
Sampling	3
Conditioning	4
Thickness	5
Load Strain Properties	6
Tear Resistance	7
Moisture Content	8
Water Absorption	9
Dimensional Stability	10
Low Temperature Flexibility	11
Heat Conditioning	12
Accelerated Weathering	13
Granule Embedment	14

High Temperature Stability 15

Precision and Bias 16

## 2. Referenced Documents

### 2.1 ASTM Standards

- D 95 Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation
- D 146 Standard Methods of Sampling and Testing Bitumen-Saturated Felts and Woven Fabrics for Roofing and Waterproofing
- D 573 Standard Test Method of Rubber Deterioration in an Air Oven
- D 751 Testing Coated Fabrics
- D 1079 Standard Definitions of Terms Relating to Roofing, Waterproofing, and Bituminous Materials
- D 1204 Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting at Elevated Temperature
- D 2523 Recommended Practice for Testing Load-Strain Properties of Roofing Membranes
- D 2565 Xenon Arc Type (Water Cooled) Light Exposure Apparatus With and Without Water for Exposure of Plastics
- D 4073 Standard Test Method for Tensile-Tear Strength of Bituminous Roofing Membranes

## 3. Sampling

3.1 From each shipment or fraction thereof select at random a number of rolls equal to one half the cube root of the total number of rolls in the lot. If the calculated number is fractional, express it as the next highest whole number. For convenience, a table, showing the number of rolls to be selected from lots of various sizes, is given in ASTM standard D 146. When mutually agreed upon by the concerned parties, other sampling frequencies may be used and reported within the framework of these procedures. The minimum sample shall consist of five rolls. The rolls so selected constitute the representative sample used for all

subsequent observations and tests pertaining to the lot of material being examined.

#### 4. Conditioning

4.1 Unless otherwise specified, condition test specimens for 4 hours at  $73\pm 4^{\circ}\text{F}$  ( $23\pm 3^{\circ}\text{C}$ ) and  $50\pm 5\%$  relative humidity prior to testing.

#### 5. Thickness. ASTM D 751

5.1 Sheet materials shall be checked at five points across the roll width, to include the weathering surface. Measurements shall be made at two points each being a minimum of six inches from each edge, and at three points equally spaced between these two points. Compute the average thickness and the standard deviation of the thicknesses based on the total number of point measurements from all of the rolls taken in accordance with section 3.

5.2 Report the individual point measurements, average, and estimated standard deviation.

#### 6. Load-Strain Properties

This method covers the determination of the load-strain (tensile-elongation, and strain energy) properties of polymer modified bituminous sheets, as set forth in ASTM D 2523 except as noted below.

##### 6.1 Specimens

6.1.1 Prepare five specimens from each sample roll in both the longitudinal and transverse directions for each temperature to be tested. Specimens shall be 1.0 in (25mm) wide by a minimum of 6.0 in (150mm) long for sheet materials having an ultimate elongation of 75% or less at  $0^{\circ}\text{F}$  ( $-18^{\circ}\text{C}$ ). Specimens shall be 0.5 in (12.5 mm) wide by a minimum of 4.0 in (100 mm) long for materials having an ultimate elongation of greater than 75% at  $0^{\circ}\text{F}$  ( $-18^{\circ}\text{C}$ ).

##### 6.2 Procedure

6.2.1 Condition each specimen at least 2 hours at the selected test temperature.

6.2.2 Test specimens at both  $73\pm 4^{\circ}\text{F}$  ( $23\pm 3^{\circ}\text{C}$ ) and  $0\pm 4^{\circ}\text{F}$  ( $-18\pm 3^{\circ}\text{C}$ ).

6.2.3 Use a constant rate of elongation (CRE) tension testing machine, preferably with automatic load



and strain recording equipment, and clamps that permit a uniform clamping pressure on the specimen without slipping. The initial clamp separation shall be minimum of  $3.0 \pm 0.125$  in ( $75 \pm 2$ mm) for sheet materials having an ultimate elongation of 75% or less at  $0^{\circ}\text{F}$  ( $-18^{\circ}\text{C}$ ), and  $2.0 \pm 0.125$  in ( $50 \pm 2$ mm) for sheet materials having an ultimate elongation greater than 75% at  $0^{\circ}\text{F}$  ( $-18^{\circ}\text{C}$ ).

6.2.4 Maintain a rate of separation of  $2.0\text{in}/\text{min} \pm 3\%$  ( $50\text{mm}/\text{min} \pm 3\%$ ) for specimens tested at  $73 \pm 4^{\circ}\text{F}$  and a rate of separation of  $0.8\text{in}/\text{min} \pm 3\%$  ( $2.0\text{mm}/\text{min} \pm 3\%$ ) for specimens tested at  $0 \pm 3^{\circ}\text{F}$ .

6.2.5 Record the percent elongation of each specimen at specimen break and also at maximum load using an extensiometer, or calculate the percent elongation at specimen break and also at maximum load from the chart of the stress versus time knowing the speed of the chart drive and the jaw separation rate.

6.2.6 Record the breaking load and maximum load of each specimen.

### 6.3 Calculation

6.3.1 Determine the percent elongation at break obtained from the extensiometer in accordance with the manufacturer's instructions, or read directly. Calculate the percent elongation determined from the chart, without an extensiometer, as follows:

$$\text{Percent elongation} = \frac{a - b}{b} \times 100 \text{ at break.}$$

$$\begin{aligned} a &= \text{jaw separation at specimen break} \\ &= \frac{\text{max. ext. on chart} \times \text{jaw separation rate}}{\text{chart speed}} \\ b &= \text{initial jaw separation} \end{aligned}$$

6.3.2 Determine the average percent elongation at break in each direction and the standard deviation of percent elongation at break in each direction based on the total number of measurements taken.

6.3.3 Calculate the percent elongation at maximum load obtained from the extensiometer in accordance with the manufacturer's instructions, or read directly. Calculate the strain at maximum load determined from the chart, without an extensiometer, as follows:

$$\text{Percent elongation} = \frac{c - b}{b} \times 100 \text{ at maximum load.}$$

$$\begin{aligned} c &= \text{jaw separation at maximum load} \\ &= \frac{\text{max. ext. on chart} \times \text{jaw separation rate}}{\text{chart speed}} \end{aligned}$$

b = initial jaw separation

6.3.4 Calculate the average percent elongation at maximum load in each direction and the standard deviation of percent elongation at maximum load in each direction based on the total number of measurements taken.

6.3.5 Calculate the average breaking load in each direction and the standard deviation of the breaking loads in each direction based on the total number of measurements taken.

6.3.6 Calculate the average maximum load in each direction and the standard deviation of the maximum loads in each direction based on the total number of measurements taken.

6.3.7 Calculate the strain energy as the area under the load-elongation (tensile-elongation) curve as obtained from the machine chart or computer system, and converted to units of lbf/in (KNM/M).

6.3.8 Calculate the average strain energy at maximum load and break in each direction and the standard deviation of the strain energies in each direction based on the total number of measurements taken.

## 6.4 Report

6.4.1 For each set of five specimens in each direction, record the temperature of the test, specimen size, individual measurements, average, and estimated standard deviation of the maximum load in lbf/in (Newtons), the breaking load in lbf/in (Newtons), the percent elongation at break, the percent elongation at maximum load, method of determining elongation, and the strain energy in in lbf/in (KNM/M) at maximum load and break.

## 7. Tear Strength

This method determines the tensile-tear strength of polymer modified bituminous sheets.

7.1 Prepare five specimens from each sample roll in accordance with ASTM D 4073. Condition specimens as set forth in section 4.

7.2 Test procedure shall be in accordance with ASTM D 4073, except that the rate of jaw separation shall be 2.0 in/min $\pm$ 3% (50 mm/min $\pm$ 3%) for testing at 73 $\pm$ 4°F.

7.3 Calculate the average tear strength in each direction and the standard deviation of the tear strength in

each direction based on the total number of measurements taken.

7.4 Report the individual specimen values, average, and estimated standard deviation of the specimens in each direction.

## 8. Moisture Content

This method determines moisture content in polymer modified bituminous sheets.

8.1 Prepare five specimens measuring approximately 4in X 4in (100mm X 100mm) from each sample roll.

8.2 Determine the mass of each specimen to the nearest 0.1 gram. Determine the moisture content in accordance with ASTM D 95. Express water as a percent of dry mass.

8.3 Calculate the average moisture content and the standard deviation of the moisture contents based on the total number of measurements taken.

8.4 Report the individual specimen values, average, and estimated standard deviation.

## 9. Water Absorption

This method determines water absorption of polymer modified bituminous sheets.

9.1 Prepare five specimens measuring approximately 4in X 4in (100mm X 100mm) from each sample roll. Seal all cut edges having exposed reinforcement with hot bitumen prior to testing.

9.2 Immerse the specimens in a distilled water bath maintained at  $122 \pm 4^{\circ}\text{F}$  ( $50 \pm 2^{\circ}\text{C}$ ) for  $100 \pm 4$  hours, remove the specimens, blot off surface water with a dry cloth, immerse the specimens in technical grade acetone for  $2 \pm 1$  seconds, and permit to air dry in laboratory for  $15 \pm 2$  minutes at  $73 \pm 4^{\circ}\text{F}$  ( $23 \pm 2^{\circ}\text{C}$ ) and  $50 \pm 5\%$  RH.

9.3 Determine the mass of each specimen to the nearest 0.1 gram after immersion. Determine moisture content in accordance with ASTM D 95. Express water as a percent of dry mass.

9.4 Determine the total percent of moisture gained by subtracting the moisture content as obtained in section 8 from the moisture content after immersion as determined in this section.



9.5 Calculate the average percent of moisture gain and the standard deviation of percent of moisture gains based on the total number of measurements taken.

9.6 Report the individual specimen values, average, and estimated standard deviation.

## 10. Dimensional Stability

This method determines dimensional stability of polymer modified bituminous sheets in accordance with ASTM D 1204, except as noted below.

10.1 Prepare five specimens from each sample roll: one specimen from each edge of the sheet and three randomly across the sheet.

10.2 Condition the specimens in an oven maintained at  $176 \pm 4^{\circ}\text{F}$  ( $80 \pm 2^{\circ}\text{C}$ ) for 24 hours  $\pm 15$  minutes.

10.3 After oven conditioning, cool the specimens and measure as indicated in ASTM D 1204.

10.4 Calculate the absolute dimensional change based on the absolute difference between the initial measurements and the measurement after conditioning for each specimen.

10.5 Calculate the average absolute dimensional change in each direction and the standard deviation of the absolute dimensional changes in each direction based on the individual results calculated in section 10.5.

10.6 Report the initial measurements of the individual specimens, measurements of individual specimens after conditioning, dimensional change in each direction for each specimen, absolute dimensional change in each direction for each specimen, absolute average, and estimated standard deviation in each direction.

## 11. Low Temperature Flexibility

This method determines the low temperature flexibility of polymer modified bituminous sheets.

11.1 Low temperature flexibility is defined as the lowest temperature recorded at which no visual signs of cracking in the membrane are observed after bending  $180 \pm 5^{\circ}$  at the desired temperature around a  $1.00 \pm 0.05\text{in.}$  ( $25 \pm 2\text{mm}$ ) mandrel in approximately 2 1 seconds.

11.2 Prepare five specimens from each sample roll in

both the longitudinal and transverse direction for each temperature to be tested. Specimens shall be  $1.0 \pm 0.05$  in. ( $25 \pm 2$  mm) wide by  $6.00 \pm 0.005$  in. ( $150 \pm 2$  mm) long.

11.3 Begin testing at a temperature where the sheet is known to pass, allowing the refrigerated unit, mandrel, and specimens to equilibrate for a minimum of 2 hours, and decrease or increase temperature in  $5 \pm 2^\circ\text{F}$  ( $3 \pm 1^\circ\text{C}$ ) increments.

(NOTE: If this information is not readily available, make preliminary screening test at  $10 \pm 2^\circ\text{F}$  intervals.)

11.4 After the specimens have been conditioned. Position the center of the specimen firmly on the mandrel weathering side up and bend the projecting ends without exerting any stress other than that required to keep the specimen in contact with the mandrel. Complete the entire procedure inside the refrigerated unit.

11.4.1 Bend the specimen until the projecting ends of the specimen are parallel to each other keeping the bottom surface in contact with the mandrel through an arc of  $180 \pm 5^\circ$ .

11.4.2 Remove the specimen from the refrigerated unit and visually inspect the specimens for any signs of cracking.

11.4.3 Repeat the above for any remaining specimens.

11.4.4 If any cracking is observed, increase the temperature in the refrigerated unit by  $5 \pm 2^\circ\text{F}$  ( $3 \pm 1^\circ\text{C}$ ). If no cracking was evident, decrease the temperature by  $5 \pm 2^\circ\text{F}$  ( $3 \pm 1^\circ\text{C}$ ). Condition ten new specimens at the next test temperature for a minimum of 2 hours. If the specimens have been pre-conditioned and the temperature change is no greater than  $5^\circ\text{F}$ , the specimens may be reconditioned for  $30 \pm 5$  min after the chamber reaches equilibrium.

11.5 Repeat section 11.3 until the lowest temperature at which none of the specimens show cracking is achieved.

11.6 Report the low temperature flexibility in  $^\circ\text{F}$  ( $^\circ\text{C}$ ) as the lowest temperature at which cracking does not occur.

## 12. Heat Conditioning

This method determines the effects of heat conditioning on polymer modified bituminous sheets.

12.1 Prepare five specimens from each sample roll in the longitudinal and transverse directions of necessary sizes for tensile, elongation, and low temperature flexibility

testing before and after conditioning. Sufficient specimen should be conditioned to accommodate subsequent testing.

12.2 Condition specimens in a forced air oven at  $158 \pm 5^\circ$  F ( $70 \pm 3^\circ$  C) for 90  $\pm$  0.25 days in accordance with ASTM D 573. Evaluate physical properties are before and after conditioning.

12.3 Report the individual specimen values, average, and estimated standard deviation for tensile, elongation, strain energy, and low temperature flexibility, as set forth in the methods for determination of these properties, before and after heat conditioning.

### 13. Accelerated Weathering

This method determines the effects of accelerated weathering on polymer modified bituminous sheets in accordance with section 7 of ASTM D 2565 except as noted below.

13.1 The irradiance shall be 0.35 W/M at 340 nm and a black body temperature of  $140 \pm 5^\circ$  F ( $60 \pm 3^\circ$  C).

13.2 Use a cycle of 60 minutes with 51 minutes arc only and 9 minutes of arc and water spray per cycle.

13.3 Expose the specimens for  $83 \pm 0.35$  cycles (2000  $\pm$  8 hours).

13.4 Orient the intended weathering surface should be toward the light source.

13.5 Expose a sufficient quantity of specimens from each sample roll for tensile, elongation, and low temperature flexibility testing after accelerated weathering. Specimens shall be cut to size and quantity after weathering.

13.6 Report the individual specimen values, average, and estimated standard deviation for tensile, elongation, strain energy, and low temperature flexibility, as set forth in the methods for determination of these properties, before and after weathering.

### 14. Granule Embedment (For granule surfaced membranes only)

This method determines granule loss on mineral surfaced polymer modified bituminous sheets.

#### 14.1 Apparatus

14.1.1 The granule adhesion testing machine is equipped with a test brush consisting of 22 bundles of steel



bristles arranged in four rows alternately. The test machine will provide a stroke such that the total abraded area on the test specimen is approximately 1.38in. X 6.77in. (35mm X 172mm).<sup>1</sup>

## 14.2 Procedure.

14.2.1 Attach the brush to the machine with the 25mm (1in) dimension of the brush parallel to the stroke line. Adjust the mass of the brush plus its holder to 5.84 lb (2650 grams) so that the downward pressure exerted on the test specimen is equal to 4.0 lbf/in (28 kPa).

14.2.2 From each sample roll prepare five specimens in the longitudinal direction with the following dimensions:  $1.38 \pm 0.05$ in. X  $6.77 \pm 0.05$ in. ( $50 \pm 2$ mm X  $229 \pm 2$ mm) and condition as specified in section 4 of this document.

14.2.3 Test each specimen individually

14.2.4 Tap each specimen to shake off any loose granules, determine the mass of the specimen to the nearest 0.1 gram.

14.2.5 Secure the specimen on the test machine with the granule surface facing the test brush.

14.2.6 Subject the specimen to 50 double strokes of the brush, remove the specimen, tap to remove any loose granules, determine the mass of the specimen to the nearest 0.1 gram.

14.2.7 Calculate the mass loss in grams to the nearest 0.1 grams after 50 double strokes for each specimen. Average the five results for the final granule loss for each sample roll.

14.2.8 Report the average granule loss for each sample roll.

## 15 Compound Stability

This method determines high temperature stability of polymer modified bituminous sheets.

### 15.1 Specimens

15.1.1 From each sample roll prepare five specimens in both the longitudinal and transverse directions for each test temperature. Specimens shall be  $2.0 \pm 0.05$ in. ( $50 \pm 2$ mm) wide by  $3.0 \pm 0.05$ in. ( $75 \pm 2$ mm) long.

### 15.2 Apparatus

15.2.1 Bulldog type clamps with smooth surfaced clamping faces at least 2 inches wide are used to suspend the specimens in a forced air oven.

15.2.2 The forced air oven shall be capable of maintaining the preset test temperature to a tolerance of  $\pm 5^{\circ}\text{F}$  ( $\pm 3^{\circ}\text{C}$ ). Set the forced air oven at  $175 \pm 5^{\circ}\text{F}$  ( $79.4 \pm 3^{\circ}\text{C}$ ), and allow the oven to equilibrate prior to testing.

### 15.3 Procedure

15.3.1 Clamp each specimen on the 2.0in. (50mm) edge with a bull dog clamp.

15.3.2 Suspend the specimen via the clamp in the forced air oven with the 3.0in. (75mm) edge of the specimen set vertically.

15.3.3 After the specimens have been conditioned for at least 2 hours 15 minutes at the specified temperature observe each specimen for signs of flowing, dripping, or drop formation on the lower edge of the specimen.

15.3.4 If flowing, dripping, or drop formation is not observed increase the oven temperature by  $25 \pm 5^{\circ}\text{F}$ , allow the oven to equilibrate and repeat procedure 15.3. Maximum temperature shall not exceed  $250 \pm 5^{\circ}\text{F}$  ( $121 \pm 3^{\circ}\text{C}$ ).

15.4 Report the test temperature at which flowing, dripping, or drop formation is observed. Provide descriptions of visible results and the number of specimens undergoing any change.

### 16. Precision and Bias

The precision and bias of these test methods as related to polymer modified bituminous sheets have not been established. Round Robin test will be conducted to establish these values.

1. As furnished by Minnesota Mining and Manufacturing Co. (3M) Industrial Products Division, St. Paul Minneapolis, MN 55101.

## **APPENDIX C. UEATC TEST PROCEDURES CITED IN THE CRITERIA**

This appendix gives the two UEATc [13] test procedures cited in the main text of the report (table 7).

### **C.1 Test for Sliding Resistance (Para. 5.1.7)**

Test only necessary for systems that are to be used on sloping roofs and is not necessary when mechanical fixing at the top of the roofing sheets is provided.

#### ***Apparatus***

A source of radiant heat.

#### ***Test Samples***

The material is bonded to a concrete slab 300 × 300 mm.

#### ***Method***

The sample is inclined at the maximum intended slope and the entire surface of the specimen is maintained at 70 °C for 7 days. Any movement is measured.

Note: For special climatic conditions, high temperatures of up to 80 °C may be necessary.

### **C.2 Unrolling Test at Low Temperature (Para. 5.4.3)**

#### ***Apparatus***

Cold room at 0 °C.

#### ***Test Samples***

A roll of the material as supplied by the manufacturer.

#### ***Method***

The roll of waterproofing is stored at 0 °C for 24 hours; on removal from storage it is immediately unrolled in approximately 15 seconds onto a flat surface.





U.S. DEPT. OF COMM. <b>BIBLIOGRAPHIC DATA SHEET</b> <i>(See instructions)</i>	<b>1. PUBLICATION OR REPORT NO.</b> NIST/BSS-167	<b>2. Performing Organ. Report No.</b>	<b>3. Publication Date</b> February 1989
<b>4. TITLE AND SUBTITLE</b> Interim Criteria for Polymer-Modified Bituminous Roofing Membrane Materials			
<b>5. AUTHOR(S)</b> Walter J. Rossiter, Jr. and James F. Seiler, Jr.			
<b>6. PERFORMING ORGANIZATION</b> <i>(If joint or other than NBS, see instructions)</i> NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY <i>(formerly NATIONAL BUREAU OF STANDARDS)</i> U.S. DEPARTMENT OF COMMERCE GAITHERSBURG, MD 20899		<b>7. Contract/Grant No.</b>	<b>8. Type of Report &amp; Period Covered</b> Final
<b>9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS</b> <i>(Street, City, State, ZIP)</i> Tri-Service Building Materials Committee			
<b>10. SUPPLEMENTARY NOTES</b> <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.			
<b>11. ABSTRACT</b> <i>(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)</i> <p>This report presents the results of a study to develop interim criteria for the selection of polymer-modified bituminous roofing membrane materials. The criteria are based on a review of existing standard specifications and related documents. They are intended for use by the construction agencies of the Department of Defense in specifying polymer-modified bituminous roofing membrane materials until voluntary consensus standards are developed in the United States.</p> <p>The suggested interim criteria are generally presented using a performance criteria format. The membrane characteristics for which performance criteria are suggested are: dimensional stability, fire, flow resistance, hail impact, moisture content and absorption, pliability, strain energy, uplift resistance, and weathering resistance (heat exposure). Prescriptive criteria for five membrane characteristics are used to complement the suggested performance criteria. The approach of using complementary prescriptive criteria is taken to incorporate in the performance criteria tests methods which can be relatively rapidly performed for characterization or identification of the membrane material.</p> <p>Other membrane requirements are listed for future development of criteria, but performance criteria for these requirements are not suggested at the present. Lack of a consistent database in the existing standards and related documents precludes suggesting criteria at this time. It is considered beneficial to present the needed criteria as a first step toward directing future research for standards development for polymer-modified bituminous roofing membrane materials.</p>			
<b>12. KEY WORDS</b> <i>(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)</i> characteristics; membranes; low-sloped roofing; performance criteria; prescriptive criteria; polymer-modified bitumens; properties; roofs; test methods			
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